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# DiVA

## Dynamic *I(V)* Analyzer

## User Manual
## Issue 3.0

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# Chapter 1: Introduction

## 1.1 Organization of the manual

The DiVA (Dynamic IV Analyzer) manual is organized into chapters and appendices as follows:

Chapter 1 Introduction
: (the present chapter) consists of conventions and nomenclature used in this document, safety guidelines, an outline of the dynamic measurement method and its basic importance, and exterior featues of the instruments.

Chapter 2 Installation and Set-up
: describes the connection of the instrument to a personal computer (PC), copying of the DiVA software onto the PC, and loading DiVA ready for setting-up with specific values as required for making a measurement.

Chapter 3 Software
: gives a description of all the software functions.

Chapter 4 Operation
: gives a worked example, step-by-step, to provide a reference for most of the important features of the instrument and typical measurement results.

Chapter 5 Running DiVA from LabView or other External Software
: contains notes to describe how to run DiVA from the software package LabView or other external software.

Chapter 6 Error Messages
: is a listing of error messages which are displayed if a fault occurs in the instrument or software, or if measurement conditions requested for a particular device cannot be met.

Appendix A Additional Examples
: gives further worked examples, mostly connected with the construction of large-signal device models for non-linear circuit simulation and design. The objective is to illustrate the methods of measurement and to state how the results are used in a typical application.



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# 1.2 Conventions

| Convention | Definition and Use |
|---|---|
| *italics* | Highlights text that you need to consider. |
| SMALL CAPS | Indicates an operating screen function. |
| **NOTE** | Indicates additional information to help the user better understand something or obtain optimum performance. Notes are not safety-related to the equipment or personnel and do not contain required reading. |
| **IMPORTANT** | Indicates information that is significant to an operation being performed or to a specific version of a product. Important information is not safety-related for the equipment or personnel, but is required reading. |
| **CAUTION** | Indicates a potentially hazardous situation which, if not avoided, could result in moderate or minor injury or damage to the machinery. It may also be used to alert against unsafe practices. |

**Table 1-1: Conventions**

# 1.3 Safety

The D265 model can output up to 65 volt at the connectors during measurements. It is recommended that an interlock switch is used on test jigs to ensure that terminals are enclosed while measurements are in progress.

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## 1.4 Nomenclature

$I_D$ , $V_{DS}$ , $V_{GS}$
: If the drain characteristics of a GaAs FET are measured with steady static bias applied, a set of curves here denoted by $I_D$ ($V_{DS}$,$V_{GS}$) is obtained.

$i_D$ , $v_{DS}$ , $v_{GS}$
: If the characteristics are measured with fast voltage pulses applied synchronously to the drain-source and gate-source, a set of characteristics here denoted by $i_D$ ($v_{DS}$,$v_{GS}$) is obtained ("fast pulses" are of typically sub-microsecond duration).

Generally, $i_D$ ($v_{DS}$,$v_{GS}$) is different from $I_D$ ($V_{DS}$,$V_{GS}$), which implies that some effect of heating, or other rate effect involving charge changes in deep levels (or traps), is occurring.

**NOTE**

*Where the text refers directly to what appears on screen in the DiVA application, the screen format is used. eg. ".id" rather than ".$i_D$" and "Most +ve VGS" rather than "Most +ve $V_{GS}$".*

## 1.5 The role of dynamic *I(V)* measurement

For many discrete GaAs FETs and integrated FETs in GaAs Monolithic Microwave Integrated Circuits (MMICs), the large-signal *I(V)* characteristics along which the device will work at RF, microwave or millimetre-wave frequencies are very different from the static characteristics - a phenomenon known as dispersion. Dispersion may also occur in some High Electron Mobility Transistors (HEMTs) constructed in various materials systems, in Heterojunction Bipolar Transistors (HBTs) and in silicon Bipolar Junction Transistors (BJTs). In GaAs FETs and HEMTs, dispersion may arise from charge changes in deep levels (or traps), or from self-heating during electrical operation. In HBTs and BJTs, self-heating is the main mechanism.

The large-signal dynamic (or RF) characteristics of a GaAs FET or HEMT, as distinct from the static characteristics, can be measured by applying fast pulses of varying amplitude synchronously to the gate and drain and sampling the drain current which flows in response. For HBTs and BJTs, the fast pulses are applied synchronously to the base and collector, and both are sampled. Generally, a given device does not possess a unique set of large-signal RF characteristics: instead, they depend upon the steady bias point about which the fast, large-signal, excursions occur. Thus, for example, the RF characteristics of a given device biased as a mixer may be quite different from the characteristics the same device will follow when biased as a class B amplifier.

Dynamic *I(V)* measurements provide, directly, the correct RF device characteristics needed for circuit design. Such measurements are also useful in helping to develop technological processes which are dispersionless, and for on-line process checks during manufacture of discrete devices and integrated circuits. Finally, the ways in which the *I(V)* characteristics change with bias point and with the length of the pulses - including the limit of pulses long enough to be considered dc - provides valuable insights into the physical processes giving rise to dispersion, and pointers to the construction of advanced large-signal models of devices for inclusion in circuit simulators to account for it.



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# 1.6 Benefits of the DiVA measurement instrument

Accent's DiVA pulsed-measurement instrument performs the function of a fast sampling curve tracer. It represents the experience of many years experimenting with the fast, large-signal response of GaAs FETs and HEMTs, initially to elucidate the physical mechanisms responsible for dispersion then, subsequently, to develop high-fidelity non-linear device models with large-signal behaviour faithful to practice for non-linear circuit design. Drawing on this background, the instrument

- has been developed as a purpose-engineered piece of equipment which is highly cost-competitive because it does not make use of expensive commercial pulse generators or power supplies;
- is driven by a personal computer running intuitive, immediately familiar Windows™-compatible software, again developed specially for the purpose; there are no switches, knobs or dials (apart from a power on/off switch and an emergency Stop button);
- makes measurements under conditions that are representative of the physical conditions which exist in practical RF, microwave and millimetre-wave circuits, thereby providing measured data immediately applicable to circuit design;
- generally assures stability (in the microwave sense) by loading the device using one of the classical techniques applied by microwave circuit engineers to prevent the measurements being corrupted by spurious oscillations;
- has been designed as a "desktop" instrument rather than as a piece of laboratory equipment, so it is compact enough to be readily portable.

# 1.7 Precautions in using the D225HR instrument

## 1.7.1 Key issue

In high-resolution mode, only devices connected straight into the instrument via a purpose-made jig without cables can be measured dependably with l00ns pulses. Measurement of devices requiring cables, as for instance devices to be probed on-wafer, are best measured on low resolution (high- and low resolution are automatically switched when the maximum collector current is set to less than l0mA (high resolution) or greater than l0mA (low resolution)).

The reasons for this cautionary advice are given below.

## 1.7.2 Output resistance of the instrument in each channel

The output resistance of the instrument, which is different for the two channels, plays an important role (in conjunction with parasitic capacitance) in determining the charging and discharging time constants affecting the pulse leading and trailing edges. The output resistance values are:



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| | Low Resolution | High Resolution |
|---|---|---|
| Base Channel | 1kΩ | 1 .5kΩ |
| Collector Channel | 100Ω | 500Ω |

**NOTE**

*High- or low resolution is automatically set depending upon whether the maximum collector current is set to less than or greater than l0mA.*

### 1.7.3 Parasitic capacitance

All sources accounted for, depending upon the connectors (but not cables) attached to the instrument, the total parasitic capacitance at the output of the instrument can be up to 30pF. Cable capacitance adds to this value. A 50Ω cable lft long will contribute another 30pF, making 60pF in all. On this basis the time constant formed by the output resistance of the base channel and a lft cable is, on high resolution, 90ns. Thus the leading edge of the pulse applied at the base terminal of the device will still be rising when the voltages and currents are sampled by the instrument, and an invalid measurement will be made.

### 1.7.4 Practical guidelines

Distilling out the regions where the shortest pulses are to be avoided, the following table gives suggested minimum pulse lengths that should be set when using the D225HR DiVA instrument.

| | No Cables | 4 inch Cables | 1 footCables |
|---|---|---|---|
| High Resolution | 100ns | 200ns | 200ns - marginal |
| Low Resolution | 100ns | 100ns | 100ns |

## 1.8 The DiVA system

### 1.8.1 Software

There are two versions of the software: Standard and Pro. The Pro version has all the functionality of the standard version, plus a few extra functions.Where a function is available only in the Pro version, this is highlighted in the software description in Chapter 3.

A standard option available with both software versions is: expansion of the software to fit one of the standard large-signal HEMT or FET model's current-voltage equations to measured *I(V)* characteristics.
Extra functionality can be added to the software on a custom basis.

### 1.8.2 Controls

All the controls for the instrument are accessed through software produced screens and dialog boxes. These screens provide a means of setting up all the parameters for device



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tests. A STOP button is provided on the PC screen and on the front of the DiVA instrument so that a measurement run can be instantly aborted in an emergency.

### 1.8.3 Host computer

The dynamic *I(V)* instrument needs to be controlled by a host, IBM PC or compatible, computer. The speed of the host machine is unimportant as all the time-critical routines involved in the testing procedures are handled by the instrument's internal processor.

The recommended minimum requirements of the computer are :

- Intel Pentium™ processor, or equivalent;
- SVGA graphics (800 x 600 with 16, 24 or 32 bpp);
- Mouse;
- one CDROM drive
- one RS232 serial communications port;
- Windows™ 2000 or XP;
- 32 MB of memory.



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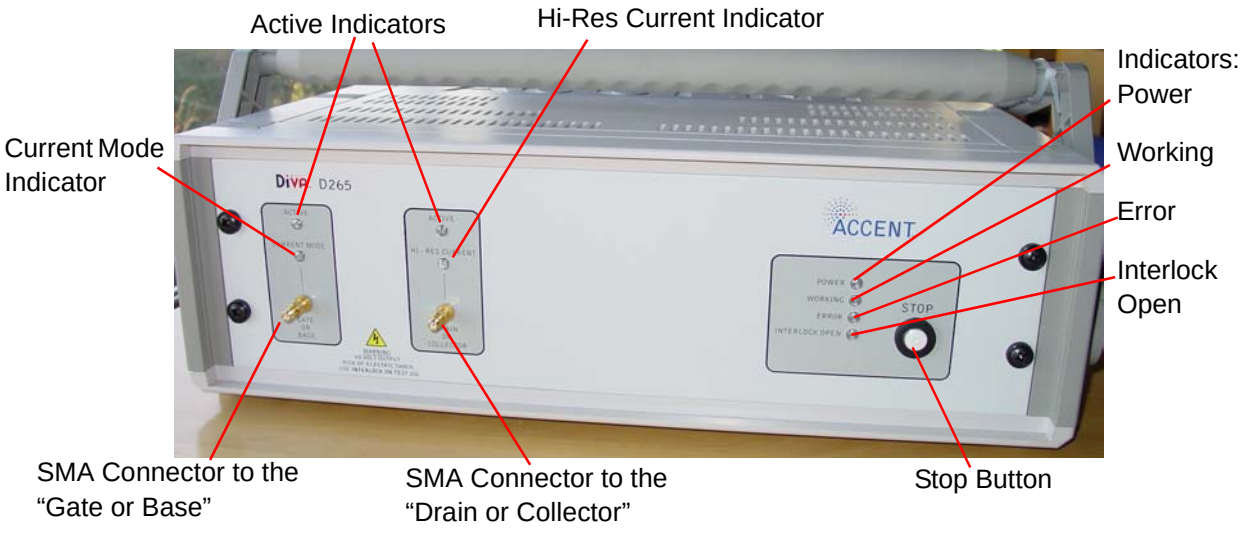
# 1.9 Exterior features visible on the instrument case

## 1.9.1 D265

### Front View




### Rear View

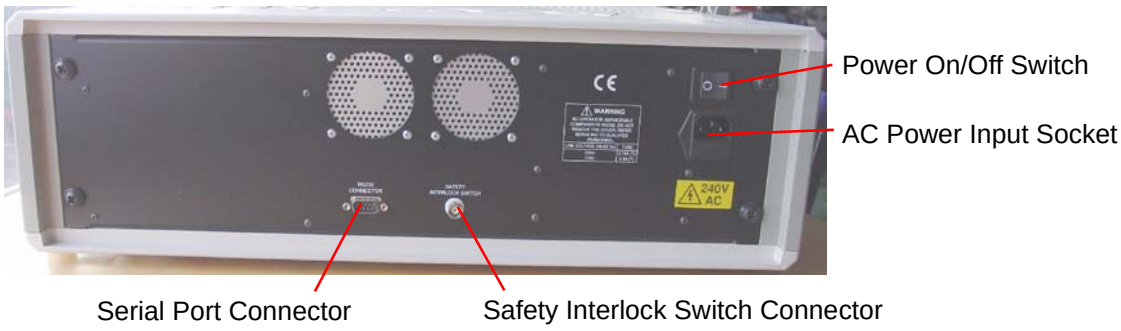



*Figure 1-1: DiVA - Exterior features*

The number of connectors, knobs and display devices on the instrument has been kept to a minimum, with all functionality possible transferred to the controlling computer software. The features visible on the instrument case are:

**AC Power Input Socket**

The AC power input socket is located on the back panel of the instrument.

**Power On/Off Switch**

The AC power On/Off switch is integral with the power input socket on the back panel of the instrument.

**Connector to Serial Port on the Controlling Computer**

There is a standard RS232 serial port connector (a male nine-way D-plug) located at the rear of the instrument. A cable is provided to connect between this socket and the active serial port on the computer on which the DiVA software is installed.



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**Safety Interlock Switch Connector**

The safety interlock should be connected to a suitable enclosure or similar safety mechanism to close the interlock circuit only when it is safe to make measurements. When the switch is open the current through the gate and drain connectors is cut off.

**SMA Connector to the "Gate or Base" of the Device Under Test**

An SMA connector is located on the lower left of the front panel.

**“Current Mode” Indicator (Amber)**

This lights to indicate when the SMA connector to the Gate or Base is providing constant current (for bipolars) rather than constant voltage.

**SMA Connector to the "Drain or Collector" of the Device Under Test**

An SMA connector is located on the front panel to the right of the "Gate or Base" connector.

**“Hi-Res Current” Indicator (Amber)**

This lights to indicate high resolution current mode (selected automatically when maximum current is set to less than 250mA).

**"Active" Indicators (Red)**

The "Gate or Base" channel and the "Drain or Collector" channel each has an LED associated with it which is lit when voltages to make the measurements are present at the connectors.

**CAUTION**

*Avoid touching any part of the connectors, cables or device under test when these LEDs are lit.*

**"Power" Indicator (Green)**

The power indicator is lit when the AC power to the instrument is turned on.

**"Working" Indicator (Green)**

The working indicator is lit whenever the instrument is performing any function connected with making a measurement and processing the results.

**"Error" Indicator (Red)**

In the unlikely event of a communications error between the instrument and the computer, this indicator will flash intermittently. Software checks to implement and monitor communication protocols have been built-in, and any errors should be detected there first and corrected. Nevertheless faults may on occasion trigger the "Error" indicator. The fault may be cleared by pressing the "STOP" button to reset the instrument.

**“Interlock Open” Indicator (Red)**

If the safety interlock is open (open circuit) this indicator will illuminate. No measurements can be made with the interlock open



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**"STOP" Button**

When this button is pressed the instrument immediately halts whatever measurement is in progress, resets the instrument and ignores any commands received from the software for the current measurement.

**CAUTION**

*Do not use the STOP button to terminate a measurement run except in an emergency. Depending upon how far the instrument has progressed through the measurement cycle, abnormally high voltages may be applied momentarily to the device-under-test, risking its destruction. If you wish to stop an otherwise legitimate series of measurements, use the software facility to cancel the run (see Section 3.5.1).*

This button should only be used without first using the software Stop function if:

1. The device under test starts smoking or exhibits other evidence of becoming hotter than is good for it;

2. A software fault occurs, preventing use of the software function.



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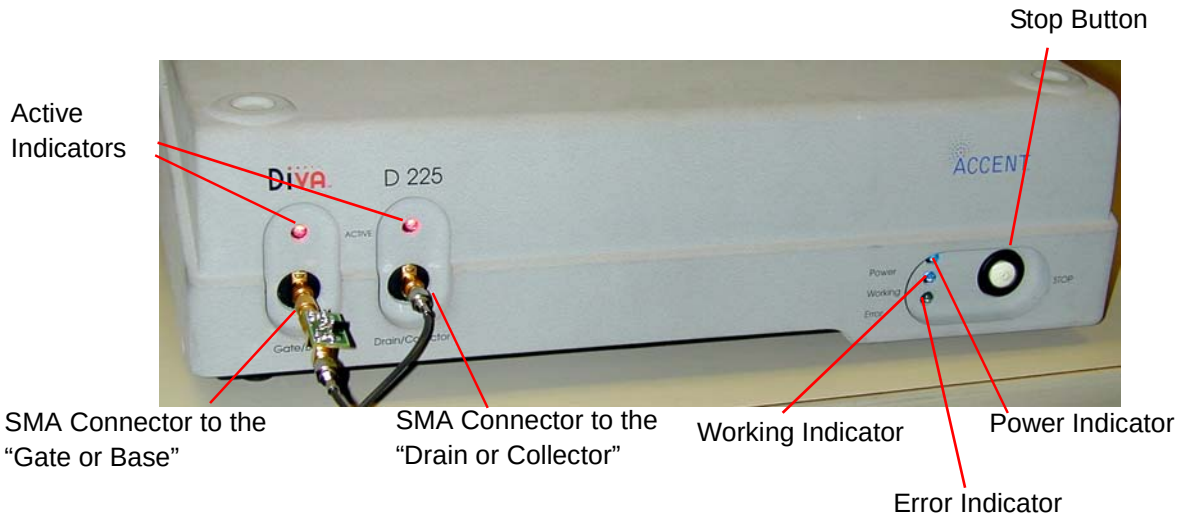
## 1.9.2 All other models

### Front View




### Rear View

*Figure 1-2: DiVA - Exterior features*

The number of connectors, knobs and display devices on the instrument has been kept to a minimum, with all functionality possible transferred to the controlling computer software. The features visible on the instrument case are:

**AC Power Input Socket**

The AC power input socket is located on the back panel of the instrument.

**Power On/Off Switch**

The AC power On/Off switch is integral with the power input socket on the back panel of the instrument.

**Power Voltage Selector Switch**

Adjacent to the power input socket is a selector, switchable between 230V and 115V.

**Connector to Serial Port on the Controlling Computer**

There is a standard RS232 serial port connector (a male nine-way D-plug) located at the rear of the instrument. A cable is provided to connect between this socket and the active serial port on the computer on which the DiVA software is installed.



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**SMA Connector to the "Gate or Base" of the Device Under Test**

An SMA connector is located on the lower left of the front panel.

**SMA Connector to the "Drain or Collector" of the Device Under Test**

An SMA connector is located on the front panel to the right of the "Gate or Base" connector.

**"Active" Indicators (Red)**

The "Gate or Base" channel and the "Drain or Collector" channel each has an LED associated with it which is lit when voltages to make the measurements are present at the connectors.

**CAUTION**

*Avoid touching any part of the connectors, cables or device under test when these LEDs are lit.*

**"Power" Indicator (Blue)**

The power indicator is lit when the AC power to the instrument is turned on.

**"Working" Indicator (Blue)**

The working indicator is lit whenever the instrument is performing any function connected with making a measurement and processing the results.

**"Error" Indicator (Red)**

In the unlikely event of a communications error between the instrument and the computer, this indicator will flash intermittently. Software checks to implement and monitor communication protocols have been built-in, and any errors should be detected there first and corrected. Nevertheless faults may on occasion trigger the "Error" indicator. The fault may be cleared by pressing the "STOP" button to reset the instrument.

**"STOP" Button**

When this button is pressed the instrument immediately halts whatever measurement is in progress, resets the instrument and ignores any commands received from the software for the current measurement.

**CAUTION**

*Do not use the STOP button to terminate a measurement run except in an emergency. Depending upon how far the instrument has progressed through the measurement cycle, abnormally high voltages may be applied momentarily to the device-under-test, risking its destruction. If you wish to stop an otherwise legitimate series of measurements, use the software facility to cancel the run (see Section 3.5.1).*

This button should only be used without first using the software Stop function if:

1. a device under test starts smoking or exhibits other evidence of becoming hotter than is good for it;

2. if a software fault occurs, preventing use of the software function.



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# Chapter 2: Installation and Set-up

## 2.1 Unpacking

**CAUTION**

*Components within the instruments can be damaged by electrostatic discharge. Observe precautions for handling electrostatic discharge sensitive devices.*

Your machine has been shipped with protective foam inserts and covers on all external data and signal ports to protect these terminals against accidental electrostatic discharge. DO NOT remove these covers until you are ready to connect the cables between units. You are advised to ground yourself to a suitably earthed point with a proprietary ESD wrist strap.

**CAUTION**

*It is important to place and use the machine on an anti-static bench in a controlled EM environment.*

If at any time the interconnecting cables are removed the protective covers should be replaced. Blue covers go on the male plugs and the red covers on the female sockets.



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# 2.2 Hardware connection

The DiVA system is supplied with standard 2m power cable. This cable may be increased in length providing that an approved IEC type connector and cable is used. However under no circumstances should the cable be substituted with a cable longer than 3m.

Due to the extremely low signals measured, some noise may be observed on the data during disturbances associated with external events such as fast transients or electro-static discharge (ESD).

Please follow the diagram below.

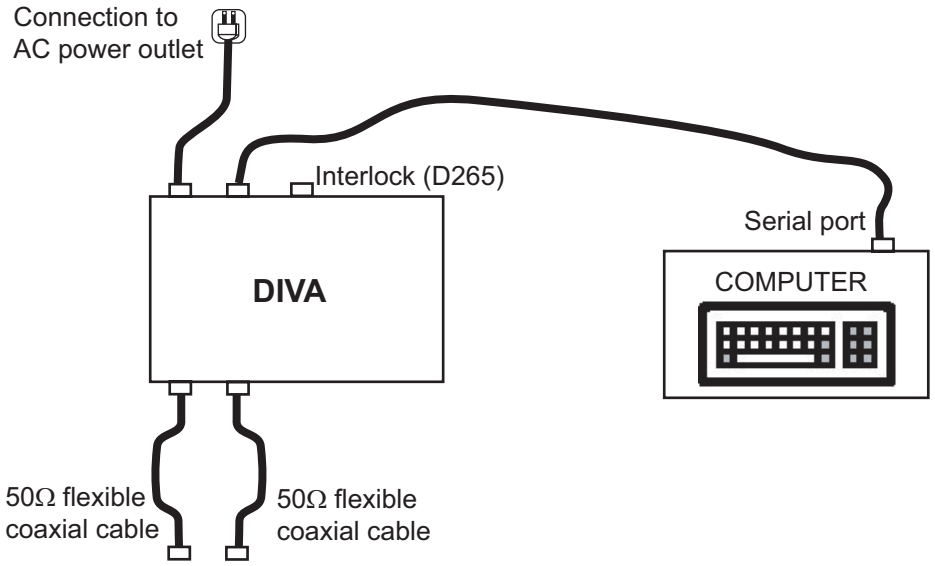


*Figure 2-1: Hardware connections diagram*

**IMPORTANT**

*An interlock is provided on the D265 to prevent the operator from coming into contact with hazardous voltages. The interlock connector on the back of the instrument must be terminated in an external short-circuit for the DiVA to operate. The intention is that the enclosure in which the device-under-test is mounted should have a door or lid which, when closed, operates a microswitch to provide the necessary short-circuit. A screened cable should be used to connect the microswitch to the interlock connector.*



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# 2.3 Connecting the device

If you wish to use a wafer prober to make contact to the device to be measured, there are some precautions which should be followed as described in the Practical Guidelines chapter of the Applications Manual (9DIVA-AM01). The present part of the manual is concerned with the short route to achieving results using simple jig mounts for packaged devices.

**IMPORTANT**

*Do not connect an oscilloscope across the device. The electrical characteristics of the oscilloscope probes and the measurement electronics will affect the output and lead to erroneous results. Neither the scope screen nor DiVA will show the true characteristics of the device.*

## 2.3.1 Suitable jigs

The jig needs to fulfil the following criteria:

1. it must be compact (i.e. electrically of small dimensions);
2. it must have SMA connectors to connect to the cables supplied with the instrument;
3. it must have no bias tees or similar structure interposed between the connectors and the device;
4. the metal strips or wires connecting the device to the SMA connectors should be short, smooth, and neat mechanical transitions;
5. the jig must be isolated from ground and from all other metal structures.



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Easily constructed example jigs are shown in Figure 2-2. Commercial microwave jigs such as those supplied by Hewlett Packards Design Techniques and HMS (Höchstfrequenz Mess-& Sensortechnik Gmbh) work well.

*Figure 2-2: Typical jigs for mounting devices for test*

### 2.3.2 Connecting the device to the Instrument

The best way to connect the device to be tested depends on the device type.

If the device to be tested is a FET or a HEMT, connect one of the flexible 50Ω RF cables supplied with the instrument to the SMA panel connector labelled "Gate or Base" on the front panel of the instrument, and connect the free end of the cable to the gate of the device via the SMA connector on the jig. If possible, connect the drain connector on the jig directly to the "Drain or Collector" output on the instrument's front panel via a straight plug-to-plug SMA adaptor. If the jig has to be sited remotely from the instrument, use the other 50Ω cable to connect the SMA panel connector labelled "Drain or Collector" to the drain of the device to be tested.

If the device to be tested is a bipolar transistor, generally best results are obtained by connecting the base of the device directly to the instrument via a straight plug-to-plug SMA adaptor, and using a 50Ω cable to connect the collector, i.e. the inverse of the connection scheme recommended for FETs and HEMTs.

**CAUTION**

*If the device is accidentally connected to the instrument the wrong way round, damage to the device will almost certainly result and there may also be damage to the instrument.*



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# 2.4 Software installation

The software installation process should start automatically after a short pause when the supplied CD is inserted in the CDROM drive. Follow the on-screen prompts to install the software as required.

In the event that the software installation does not start automatically, it can be initiated by double clicking on the ‘Setup.exe’ file, located on the CD.

This manual is also provided on the CD in Adobe Acrobat format and can be viewed using the freely available Adobe Acrobat reader. This reader is not supplied on the CD; the latest version can be obtained from Adobe or downloaded freely from their website.



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# Chapter 3: Software

This chapter describes the broad functioning of the software and provides details of those functions that are not measurement type dependent.

## 3.1 File structure

The DiVA software sets up a Projects folder in the same directory as the .exe file for storing results. It creates a project file (extension .pul) that contains the measurement settings and selections entered by the user and a folder for each project containing the measurement results files (extension .div), where pul is from pulsed instrument and div is from DiVA.

## 3.2 Starting the program

Start the DiVA program using any of the standard Windows™ methods for launching AutoRunner.exe. During the process of loading, the transitory screen shown in Figure 3-1 displays the program version number. The program version number will also be displayed when the mouse pointer is held over the DiVA logo in the bottom left of the main screen (see Figure 3-3).

*Figure 3-1: Transitory opening screen*

The software looks for the presence of a DiVA instrument and assertains the model. If no DiVA is connected, a dialog box (see Figure 3-2) eventually appears to tell you that no instrument has been found and giving you the opportunity to continue regardless by pressing the Cancel button.

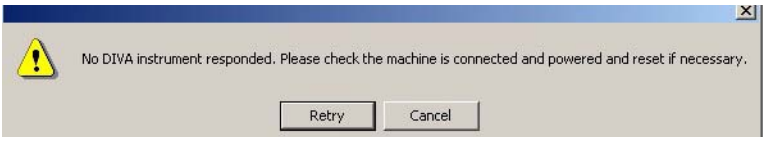


*Figure 3-2: No DiVA connected message*



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# 3.3 Main screen

Screen convention

Buttons that are greyed are not available. The reason for unavailability is described in the message bar, above the DiVA logo, when the mouse is held over the button.

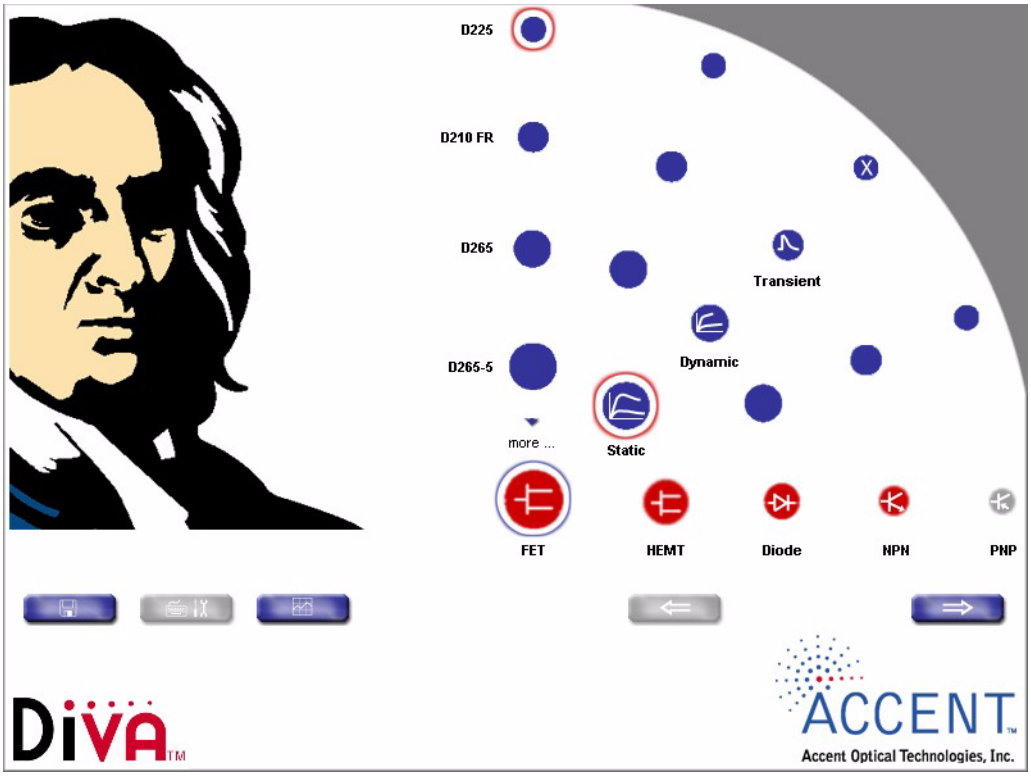


*Figure 3-3: Main screen*

The right-hand section of the screen is the first of two setup screens and is for selecting the device and measurement type. The DiVA instrument is automatically recognised and selected and should only be overridden if no instrument is connected. Refer to Section 3.4 and Section 3.5 for a full description of the setup screens.

The menu bar (located in the lower left of the screen) enables file handling operations and graph opening. It consists of the following buttons:

File Menu - see Section 3.6

For configuration and future options. Not applicable to this version.

Show Graphs - see Section 3.7

Context-sensitive help messages are displayed below this menu bar.



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# 3.4 Measurement definition

The required measurement is defined in the right-hand section of the main screen (see Figure 3-4). Selected options are indicated by red/blue halos.

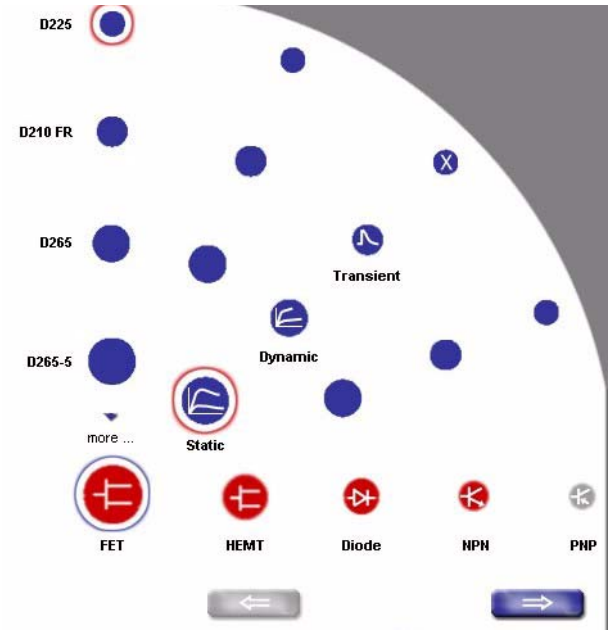


*Figure 3-4: Measurement definition section of the main screen*

The DiVA instrument connected at power up time is automatically recognized and denoted by a red halo, as shown for the D225 in Figure 3-4. If it is necessary to select the instrument (see Caution below) and the required model is not displayed, click on the arrow to display other instrument variants.

DiVA is designed to measure the static, dynamic and transient characteristics of HEMTs and FETs, NPN bipolar transistors, diodes, and, depending upon the instrument variant, PNP bipolar transistors.

Select the device to be measured from the options in the horizontal line of red circles. Devices that cannot be measured on the detected/selected instrument are grayed and not available for selection.

Finally select the type of measurement to be made, from those available, for the selected device.

Having completed the specification, the parameters for the measurement must now be set. A set of fields, variable according to the measurement specification, will be presented when the right arrow button is pressed. See Section 3.5.



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# 3.5 Measurement parameters

A typical measurement parameters screen is shown in Figure 3-5.

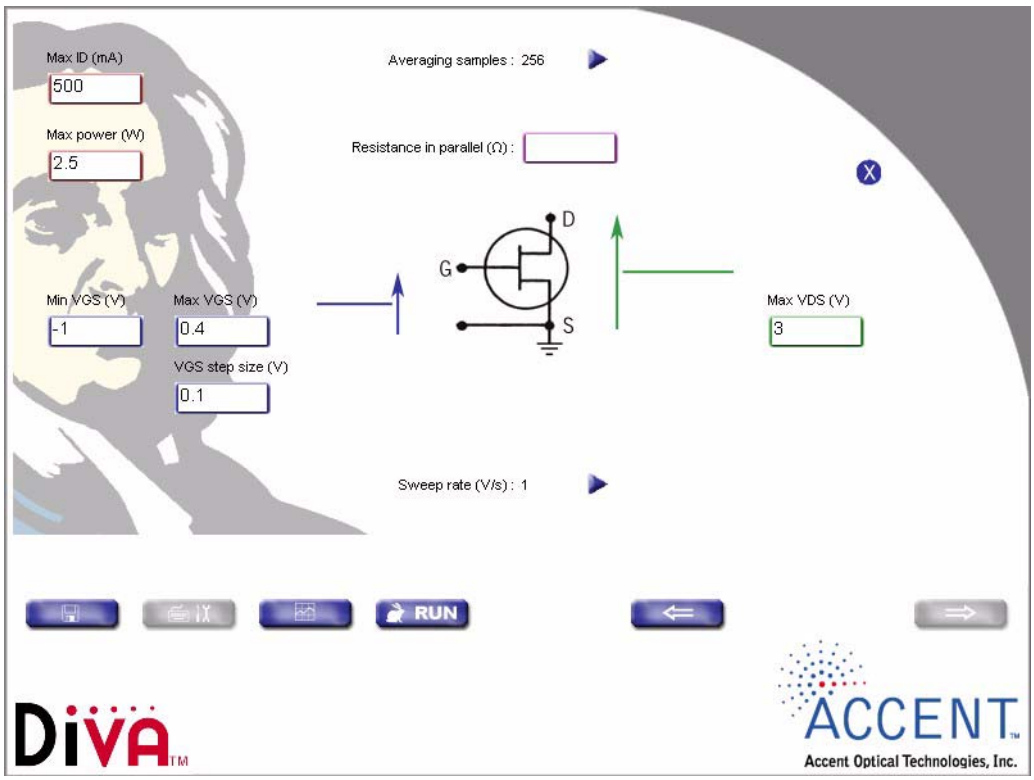


*Figure 3-5: Typical measurement parameters screen*

When setting up a new measurement, the default values are selected or displayed on entry to the screen. The parameters are grouped by application and colour coded. Change the data as follows:

Where a box contains a value on entry, edit the value as a normal text field.
If the field is empty, enter a value if necessary.
Hold the mouse over the field name to display the value limits.

The currently selected value for this field is displayed. To change the value, click on the arrow to produce the drop-down selection box then click on the required value to select it.



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## 3.5.1 Run


Before using this button to start the run it is important to save the field settings, using the SAVE function in the FILE MENU to update an existing project file or enter the name for a new project. If a new project name is entered, a new folder will be created automatically, when the measurement is made, to store the results.

Click on this button to start a single measurement once all parameters for it have been set.

Once the measurement has started the Run button will change to

. Click on it when it is necessary to halt a measurement run for other than emergency reasons e.g. to change the step size.

When STOP is selected the software ceases communication with the DiVA instrument and waits for it to complete its current operation before allowing any new measurement to take place.

Exiting the program during a measurement has the same effect, pausing the program momentarily to allow the DiVA instrument to complete its current operation.

It is not necessary to press the STOP button on the DiVA instrument.

**CAUTION**

*Do not use the STOP button on the DiVA instrument to terminate a measurement run except in an emergency. Depending upon how far the instrument has progressed through the measurement cycle, abnormally high voltages may be applied momentarily to the device-under-test, risking its destruction. If you wish to stop an otherwise legitimate series of measurements, use the software facility, described above, to cancel the run.*



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# 3.6 File menu

**NOTE**

*The functions in this menu are related to Project (.pul) files only, not measured data files. Measured data files may be accessed by selecting Show Graphs (see Section 3.7).*

Displays the file menu bar as shown in Figure 3-6.

*Figure 3-6: File menu bar*

## 3.6.1 Load

Use this button to Load/Open an existing project file.

Press LOAD to display a standard Windows™ Open file dialog box and select the required project file (.pul). Loading a project file will update values in the main screen to reflect the contents of the project file, overiding any previous values chosen.

## 3.6.2 Save

This button will be available if any changes have been made to project data.

Press SAVE to display a standard Windows™ Save file dialog box.

Save to the same name to update the project file.
Save to a new file name to create a new project file.

## 3.6.3 Automate

This function is available in the Pro version of the software only.

This button provides an easy way of creating an automation file (.dar) which can be used to run the DiVA instrument from other software or in a batch mode, without having to go through the interactive menus. Detailed information about automation is contained in Chapter 5 . Press AUTO to display the screen shown in Figure 3-7.

The context-sensitive help for this screen is displayed at the top.

Automation File:

Left click on the file name to open a standard Windows™ Save file dialog box.
Save to the same name to update the current automation file.
Save to a new name and/or location to create a new automation file.

Click on the ARROW to open a standard Windows™ Open file dialog box to open a different existing automation file.



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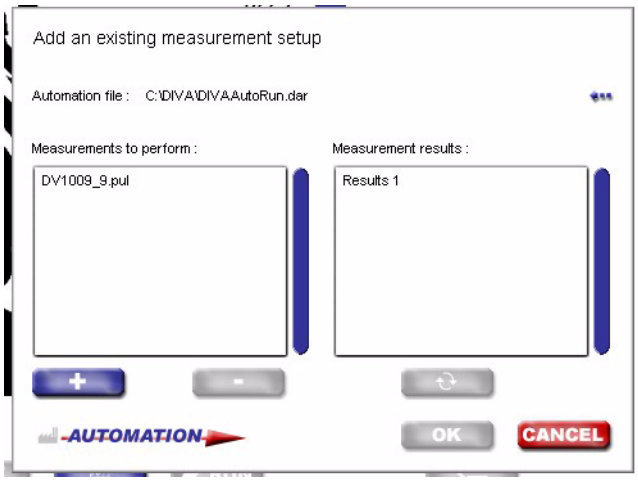


*Figure 3-7: Automate setup screen*

Measurements to perform:

This box lists measurements that will be performed by this automation file.

To add a project file to the list, click on the PLUS button to open a standard Windows™ Open file dialog box. Select a project and press Open to add it to the list.

Use the MINUS button to remove projects from the list.
Select a project (the MINUS button becomes available) then click on MINUS to remove it from the list.

Measurement results:

This box lists the output measurement file names for the corresponding project.

To rename an output file, select the file and the RENAME button becomes available. Press RENAME to open a standard Windows™ Save file dialog box. Enter the required name then press Save.

Press to proceed with the execution of the listed projects.

Press to exit from the automation setup screen without running measurements. Note that unsaved changes will be lost.



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# 3.7 Show graphs

The Show Graphs button opens a screen that enables data manipulation and display. The functions available in this screen include:

- Displaying single graphs of measured data
- Displaying two sets of comparable measured data on one graph
- Printing graphs
- Saving graphs as meta-files for export to other software applications
- Data manipulation to allow data to be placed on a regular grid
- Data manipulation allowing change of variable e.g. ID(VGS) to be plotted
- Export of data to different formats such as CITI and MDM files for IC-Cap
- Fitting of standard large-signal models to measured data.

**IMPORTANT**

*The software saves all data returned by the instrument, which can lead to some very large files. On some PCs these files may take a long time to load, giving the appearance that the system has hung. Large files may arise for dc measurements and where a large number of parameter steps have been chosen.*

When a set of data is loaded it is displayed together with a title (at the top of the window), which is initially the file name. This title is simply a character string that may be changed, but it should be noted that, once the file name is removed, there is no indication of the file from which the graph was created.

Press the SHOW GRAPHS button to open a standard Windows™ Open file dialog box. Select the file whose graph you wish to display and press Open. The graph screen displaying the chosen data file will appear as shown in Figure 3-8.

Functions of the various elements displayed around the graph are:

Graph Options

This opens a window that provides most of the manipulating and viewing functions (see Section 3.7.1).

Scroll through loaded data

These symbols are only visible when more than one set of measurement data is loaded.

Throw Away

Close the current data file(s).



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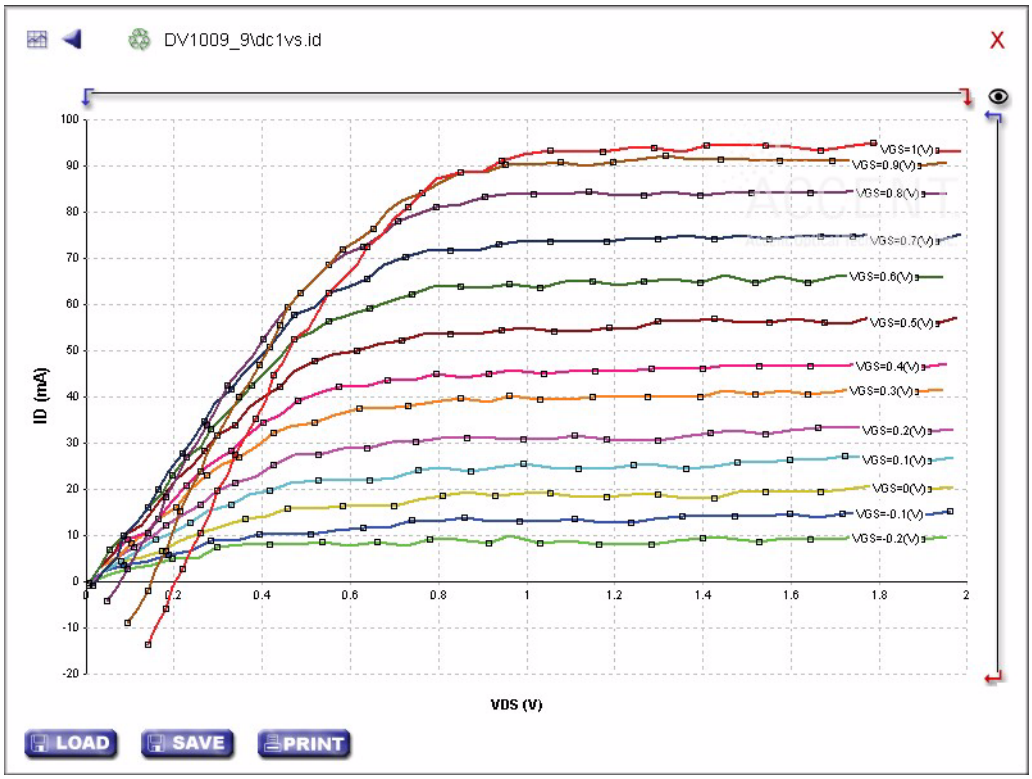


*Figure 3-8: Graph screen*

Close X

Close the graph window.

Zoom

Use the arrows to zoom in to a particular area of a graph.

Click on to return the axis to the full automatic scale.

Open Existing LOAD

Use this button to load an existing measurement data file (.div). The button opens a standard Windows™ Open file dialog box.

Export graph SAVE

This function is available in the Pro version of the software only.

Use this button to save or convert the current graph for use in a third party application.

Print graph PRINT

Prints the current graph and legend at the maximum available resolution. The button opens a standard Windows™ Print file dialog box.

Note that before printing you may change the title of the graph. The file name is a text field that may be edited in the standard way.



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## 3.7.1 Graph options

Click on this symbol to open the graph options dialog box where the data may be manipulated and the graph display changed.

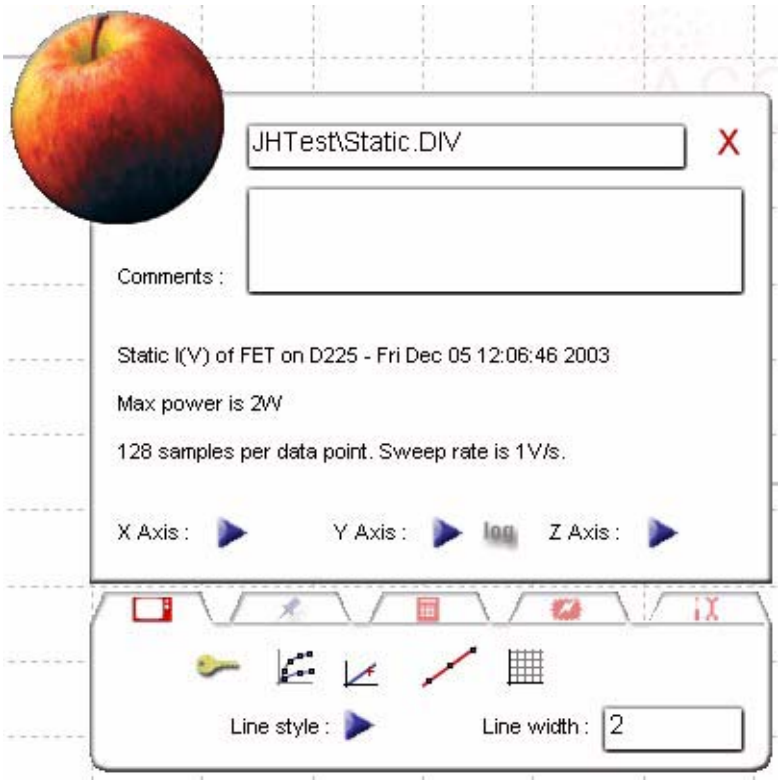
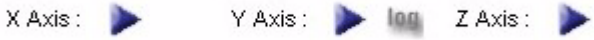



*Figure 3-9: Graph options dialog box*

Text may be entered in the Comments box. When the graph is saved this comment will be stored with the rest of the measurement data.




Clicking on the arrow at the side of an axis name will produce a list of the variables that can be plotted on that axis, with the current variable highlighted.

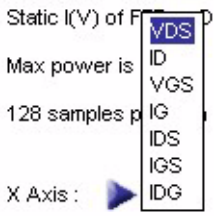



*Figure 3-10: Graph axis selection*

**NOTE**

*The z-axis represents the variable for which the graph is plotted. This choice is only relevant to measurements made on software version 3.0 onwards where all measurement data is stored in a single file. In older*



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*versions a maximum of three variables are stored in a single file, so there is no choice to be made.*

Where log is displayed at the side of an arrow, clicking on the symbol will convert the axis to a logarithmic scale. The symbol will then become log . Click on this symbol to return the axis to a linear scale.

The tabbed pages in the lower part of the dialog box are described in the following sections.

### 3.7.1.1 Display Options

The options here affect the way the data is displayed in the graph.

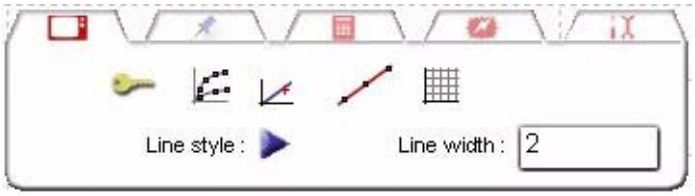


*Figure 3-11: Graph Options - Display Options page*

The displayed symbol shows the current status of each selection. Click on the symbol to toggle to the other option.

Legend

Show graph line legends on the screen

Hide graph line legends.

Data Points

Show data points

Hide data points.

Bias Point

Show bias point when it is in range

Always show the bias point.

Data Point Density

Show only a selection of data points

Show all data points.

**NOTE**

*This option will have no effect if data points are hidden.*

Grid

Show the grid

Hide the grid



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Line Style

Click on the arrow to produce a list of the styles available, with the current style highlighted.

*Figure 3-12: Graph Options - Line style selection*

Click on the required style to highlight it and close the list.

Line Width

Enter a number to set the thickness of the graph lines, or size of the symbols. The default value is 2, with 1 selecting a finer line or smaller symbols.

### 3.7.1.2 Compare Graphs

This option allows multiple measurement data files to be displayed on the same graph for comparison.

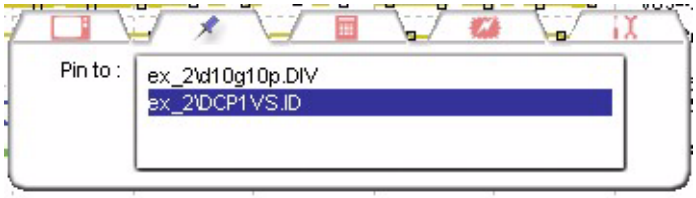


*Figure 3-13: Graph Options - Compare Graphs page*

The display shows all loaded measurement data files, other than the one currently displayed. Highlight the file(s) you wish to compare with the current file (use Ctrl+click for multiple files) and you will see it(them) appear overlayed in the graph window. In order to distinguish between curves, open the Display Options box (see Section 3.7.1.1) and change the style of each graph **before** overlaying them. To remove graphs from the display, use Ctrl+click to deselect them.

### 3.7.1.3 Resample Data

This option allows the data to be replotted on modified axes, but only one axis should be changed (X or Y **not** both).

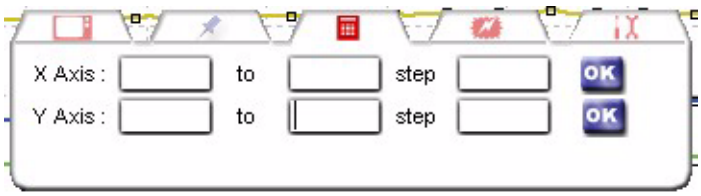


*Figure 3-14: Graph Options - Resample Data page*

This option should not be confused with changing the graph scale (Section 3.7.1.5). Use this option to place data, by interpolation, on a uniform grid. This is especially useful prior to switching axis e.g. prior to changing from plotting I($V_{DS}$) to plotting I($V_{GS}$).



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### 3.7.1.4 Graph Wizard

This option provides tools for deriving information from the data for use in other, third party, applications e.g. MicroWave Office..

*Figure 3-15: Graph Options - Resample Data page*

Fit to model


Click on this button to open the dialog box for model fitting:

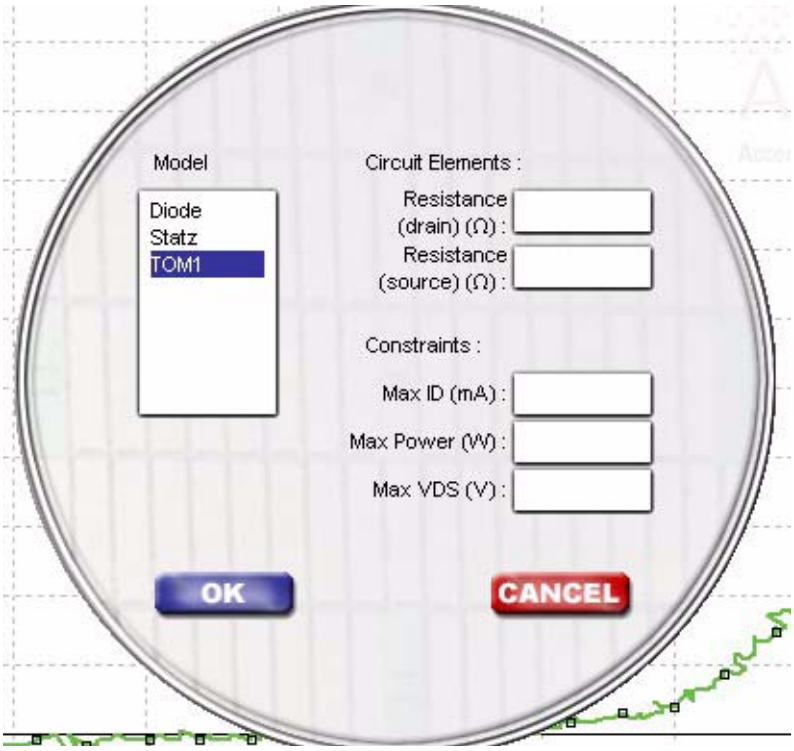


*Figure 3-16: Model selection dialog box*

1. From the list of available models, select the one to use for fitting the data.
2. Enter the circuit resistances and the constraints that are to be placed. If the boxes are left blank, default values of no constraints and zero resistances will apply.
3. Click on OK.
   In the dialog box that opens, select the file that the model is to be fitted to then click on Open. The output file name will be created automatically, based on the name of the input file and the model name.

**NOTE**

*Although the file may already be displayed in the graph window it must still be specified here.*



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The values of the fitted model parameters are stored in simple text form in the output file. The parameter values may then be used in a circuitry simulator by simply entering them in the appropriate model entry dialog in the circuit simulator.

4. Click on Cancel to close the dialog box without fitting.

### 3.7.1.5 Graph Scale

This option enables the graph axis to be set to any range required and is provided to assist with graph presentations.

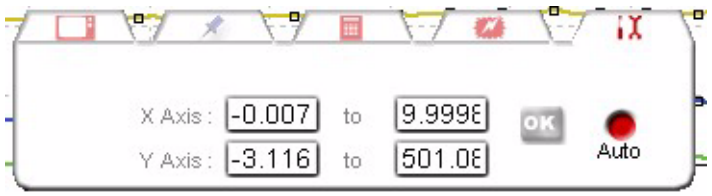


*Figure 3-17: Graph Options - Graph Scale page*

Click on the Auto button to make the other fields available (the OK button will be blue). Set the required axis ranges then click on OK.

**NOTE**

*The Auto button cannot be used to return to the automatic scale based on the data. To return to this scale, click on the zoom symbol*



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# Chapter 4: Operation

This chapter provides a comprehensive description of the most common operations of the instrument. It does so by going through the process of measuring the difference between the slow-sweep (or static) characteristics of a GaAs FET and the large-signal RF (or dynamic) characteristics.

**IMPORTANT**

*The software saves all data returned by the instrument, which can lead to some very large files. On some PCs these files may take a long time to load, giving the appearance that the system has hung. Large files may arise for dc measurements and where a large number of parameter steps have been chosen.*

## 4.1 Readying the instrument and the DiVA software

**IMPORTANT**

*It is important to place and use the machine on an anti-static bench in a controlled EM environment and to ground yourself to a suitably earthed point with a proprietary ESD wrist strap.*

**CAUTION**

*If the device is accidentally connected to the instrument the wrong way round, damage to the device will almost certainly result and damage to the instrument may result.*

1. Ensure the AC power selector switch is set to the local power supply voltage and that the instrument is connected to the AC power supply, that the instrument is connected to the serial port on the computer with the cable supplied, and that the DiVA software is installed.

2. Turn power to the instrument on 30 minutes or more before making measurements. A resistor will give an offset if the instrument is not completely warmed up.

3. Connect the device-to-be-tested to the instrument following the guidelines in Section 2.3.

4. Start the DiVA program.



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The limit values for a GaAs FET or HEMT are $I_{MAX}$, the maximum positive value of $V_{GS}$, the pinch-off voltage $V_P$ , $V_{DSMAX}$ and $P_{MAX}$. If these values are known they may be set into the DiVA software following the procedure described in Section 4.4. For illustrative purposes, we will assume that the limit values are not known, thereby making it necessary to work through a preliminary procedure to find them.

# 4.2 Preliminary tests to find a reasonable operating range for the device

The work in this section is necessary only when the device's operating limits are not known, so it becomes necessary to find a reasonable operating range for the device.

**CAUTION**

*The values recommended in this section are reasonable for the average FET or HEMT. If, however, you have devices with very short gates (less than 0.25µm), small gatewidth (less than 50µm) or features which could lead to a low breakdown voltage (such as a single, deep but narrow, gate recess on heavily doped layers) then the numbers recommended may cause the destruction of your device. Proceed with caution, and use smaller values if you are unsure!*

## 4.2.1 Preparing for a new measurement

In the main screen the instrument should be automatically detected (in this case D225). Failure to detect the instrument will raise an error and will require restarting the software after correction of the problem. You may use the software with no instrument connected, manually selecting the instrument, but the ability to run measurements will be disabled. Select the device to be measured and the measurement to be made.

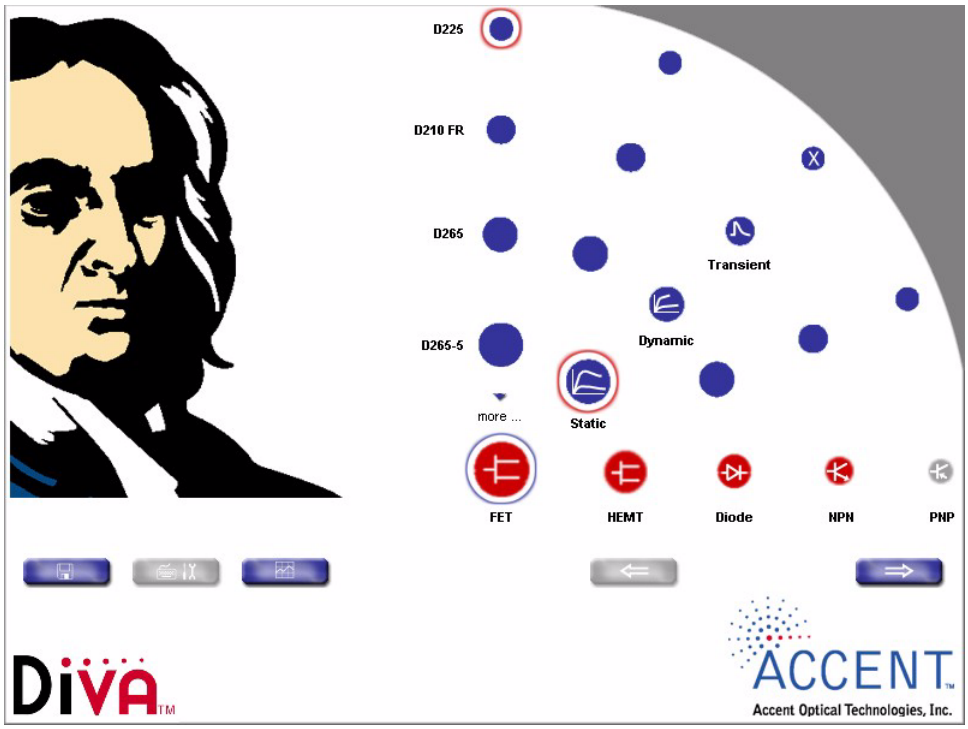


*Figure 4-1: Defining the measurement*



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Click on to display the parameter screen shown in Figure 4-2. The screen is shown with values entered as described in the paragraphs following.

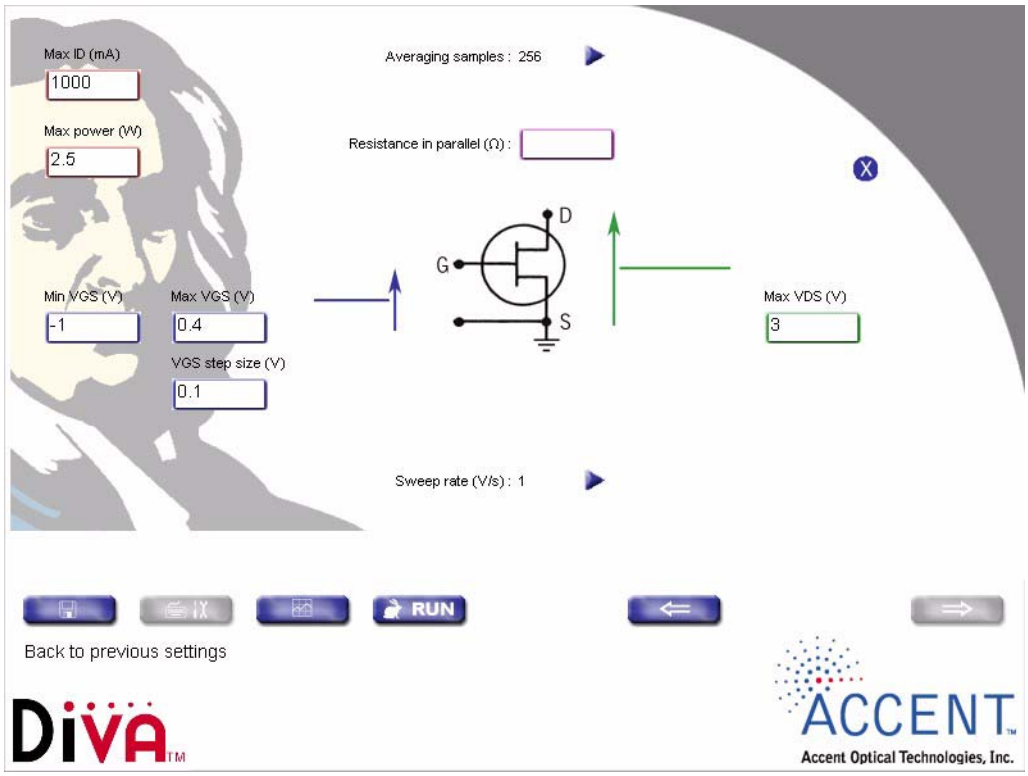


*Figure 4-2: Trial limits for measurement of Static I(V) characteristics*

Min VGS (V)
To avoid the risk of over-driving the gate in the reverse direction, enter -1.

Max VGS (V)
To avoid the risk of over-driving the gate in the forward direction, enter 0 (zero) (see Note[1]).

VGS step size (V)
For this exercise select 0.5.

Max VDS (V)
To avoid the risk of over-driving the gate-drain in the reverse direction, enter 3.

Max ID (mA)
This is the maximum drain current that the instrument will allow the device to pass. Since we have already set the maximum positive $V_{GS}$ at $V_{GS}$ = 0V, the maximum current the device can pass is $I_{DS}$ which, almost by definition, should be a safe current. Consequently, the maximum current may as well be set to the instrument's rating, which is given in the appropriate DiVA model data sheet.

1. If the device happens to be an enhancement-mode FET or HEMT, the maximum $V_{GS}$ just set, $V_{GS}$ = 0V, will lead to no drain current flow. In that case, a higher value must be set, for instance +0.4V.



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Max power (W)

To protect the device from destruction by self-heating, a limit must be set for the instantaneous power the instrument will permit the device to dissipate. A reasonable rule is to take

$$\frac{(V_{DS} \times I_{MAX})}{3} \text{ to } \frac{(V_{DSMAX} \times I_{MAX})}{2}$$

Using the present illustrative values,

$$P_{MAX} = \frac{(3\text{V} \times 500\text{mA})}{2} = 0.75\text{W}$$

Averaging samples :

This is a number used to reduce the noise in the measured current by averaging over that number of samples.
For this exercise set the value to 128.

Resistance in parallel (Ω) :

If an external resistor has been placed in parallel with the device-under-test in order to stabilise it, insert a resistance value here. For most devices stabilising resistors should not be needed so the box should be left blank or a zero value entered (zero is taken to mean no resistor present rather than a zero-resistance short-circuit to ground).

The software uses the value of this resistance to correct the curves for the extra current that flows through the stabilising resistor rather than through the device itself.

Sweep rate (V/s)

Sweep rate refers to the rate at which $V_{DS}$ is increased (in volts per second) to make a static *I(V)* measurement.
For this exercise select 1.

This number sets the rate at which the drain-source voltage is applied to the device as a continuous sweep. 0.1V/s is slow enough for the thermal dissipation in the device to be in steady (but slowly changing) state with the voltages applied and so may be regarded as constituting a true static measurement. 10V/s is fast enough for some devices not to reach a thermal steady state.

If too fast a sweep rate is used so that thermal equilibrium is not reached, the current at the bias point during dynamic measurements will differ from the value shown on the static curves.

Once all fields are set, click on FILE MENU and then

. Select an existing project file or enter the name for a new project. If a new project name is entered, a new folder will be created automatically when the measurement is made to store the results.

Click on

to start the measurement (see Section 4.2.2).



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## 4.2.2 The measurement run

When the instrument is actively making measurements on the device, the two red LEDs above the "Gate or Base" and "Drain or Collector" panel connectors are lit, and the blue(green) "Working" LED on the bottom right of the front panel is lit. The red LEDs then go out and the blue(green) LED remains lit to indicate that data acquired during the measurement phase, stored temporarily in the instrument's memory, is being transmitted to the computer's memory. This cycle of events, which may take several tens of seconds to several minutes depending upon the measurements requested, is repeated for each gate voltage (or base current) set by the operator in the set-up. Between each cycle the blue(green) working light goes out while the instrument waits for the next measurement request to be sent. A progress message is displayed on the status bar.

The measurements are complete once the blue(green) working light is out (not lit) for more than a few seconds **and** the RUN button on the screen becomes available again.

For the particular GaAs MESFET used in this example, the values used in the set-up lead to the following ID/VDS graph display:

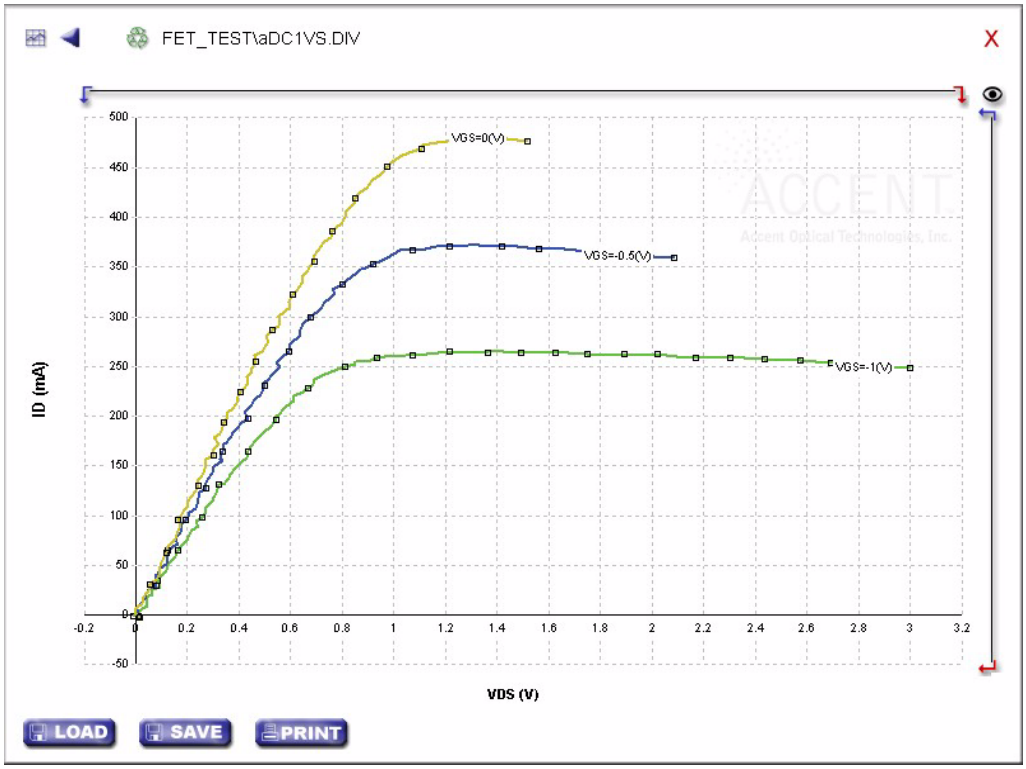


*Figure 4-3: Trial Static I(V) measurement id graph results*

Although obviously an incomplete set of characteristics, from this display revised limits can be calculated (as in Section 4.3 to Section 4.3.5) which will allow a complete set of device characteristics to be measured.



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# 4.3 Calculating practical limits

Given that the device does not reach pinch-off, the values set as limits evidently are too conservative and must be re-set to more realistic values in the set-up. With the information provided by the test just done, a systematic procedure is possible.

Choose a fixed $V_{DS}$ value, say $V_{DS}$ = 2V, and find the drain current at two values of $V_{GS}$, say $I_{D1}$ at $V_{GS1}$ and $I_{D2}$ at $V_{GS2}$ (where the $V_{GS}$ values are expressed as negative numbers and $V_{GS2} < V_{GS1}$, i.e. $V_{GS2}$ is more negative than $V_{GS1}$). Recognizing that the extrinsic transconductance is approximately

$$g_M = \frac{I_{D1} - I_{D2}}{V_{GS1} - V_{GS2}} \qquad (1)$$

a value for $g_M$ can be calculated. For the device in this exercise: at $V_{DS}$ = 2V,
at $V_{GS1}$ = -0.5V, $I_{D1}$ ~ 350mA ; at $V_{GS2}$ = -1.0V, $I_{D2}$ ~ 250mA
so $g_M$ ~ 200mS

## 4.3.1 Estimating the pinch-off voltage

Re-arranging equation (1) after setting $I_{D2}$ = 0 and $V_{GS2} = V_{P\ estimate}$ ;

$V_{P\ estimate} = V_{GS1} - I_{D1}/g_M$

For the present example

$V_{P\ estimate}$ ~ -0.5 - (350/200) = -2.3V

A value for the true pinch-off voltage must allow for the decrease in transconductance which occurs with decreasing drain current i.e. the true $V_P$ will be a more negative number than $V_{P\ estimate}$. We calculate $V_P$ as an integer multiple of an available $V_{GS}$ step option, based on $V_{P\ estimate}$ for later entry in the "Min VGS (V)" edit box in the set-up window.

For this exercise, we take -3V, being (6 x -0.5)V.

## 4.3.2 Revising the $V_{GS}$ step size

The $V_{GS}$ step should be revised to the value used in the preceding section (i.e. 0.5V in this exercise).



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### 4.3.3 Estimating a value for $I_{MAX}$ for positive $V_{GS}$

If you wish to measure the drain current characteristic for positive $V_{GS}$, equation (1) can be applied to estimate a value for $I_{MAX}$ and this value, instead of $I_{DS}$, can later be entered in the "Max ID (mA)" box.

### 4.3.4 Finding a safe limit $V_{DSMAX}$

In practical devices, breakdown voltage is often one of the most variable parameters among nominally identical samples of the same device type. Hence it is appropriate to find the limit sample-by-sample. The following procedure presents little risk of destroying the device but requires a further experiment. The idea is to find that value of $V_{DS}$ at which, for $V_{GS} = V_P$ , the drain current $I_D$ reaches $0.1I_{DS}$, where $V_P$ will typically be -ve for a depletion mode device and +ve for an enhancement mode device.

To prepare for the experiment, set values as follows in the set-up screen;

| | |
|---|---|
| Max VGS (V): | $V_P$ |
| Min VGS (V): | $V_P$ - 0.1V |
| VGS step size (V): | 0.1V |
| Max VDS (V): | 10V |
| Max ID (mA): | $I_{DS}/10$ |
| Max power (W): | 10V x $I_{DS}/10$ |

The device is unlikely to be damaged even if the drain current starts to increase rapidly due to impact ionization (breakdown) in the gate-drain region because the instrument automatically stops the measurement as soon as the current limit is reached.

The safe working limit may be taken to be the value of $V_{DS}$ at which, for $V_{GS} = V_P$ , the drain current reaches the value $I_{DS}/10$.

### 4.3.5 Estimating a safe limit for $P_{MAX}$

A reasonable estimate is that suggested in Section 4.2.1, i.e. between

$$\frac{(V_{DSMAX} \times I_{MAX})}{3} \text{ and } \frac{(V_{DSMAX} \times I_{MAX})}{2}$$

The revised value can later be set in the "Max power (W)" box . For the present device 2W will be used.



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# 4.4 Measuring static characteristics

The voltage and current limits which constrain the measurement should be available from one of two sources: either from the device manufacturer's data sheets, or from the procedure of Section 4.2 and Section 4.3.

Close the graph window then, if necessary, click on to enter the new limits. For this exercise the parameters set-up screen should now appear as:

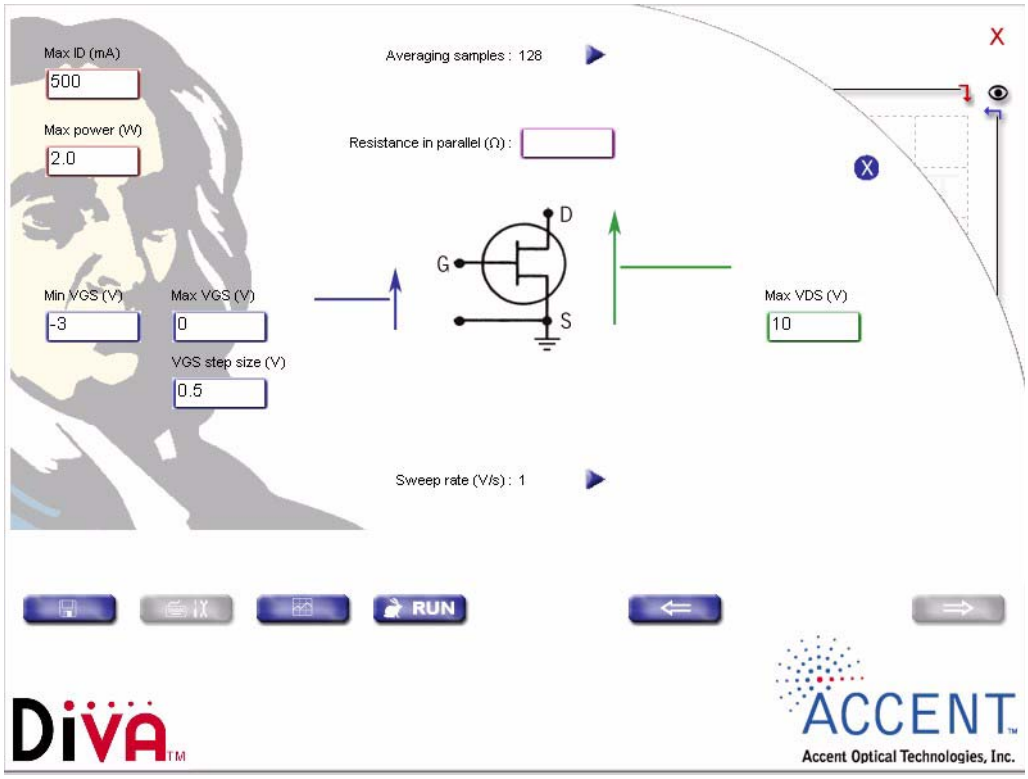


*Figure 4-4: Practical limits for measurement of Static I(V) characteristics*

Press to start measurement of the device characteristics with practical limits, resulting in (for this exercise) the graphs shown in Figure 4-5.

These are now the full-range static characteristics of the device.

Use the graph options to cutomize the graph (see Section 3.7.1).

In this particular device, which is a commercial GaAs FET for use in mobile 'phone handset RF power amplifiers, there is pronounced negative differential conductivity in the static drain characteristics at the higher drain currents. This negative slope is only partly due to self-heating: much of it is due to bias-dependent changes in the charge held in deep levels (or traps) located on the semiconductor surface between the gate and the drain, and between the gate and the source. *As will become apparent in Section 4.5, this negative slope is not present when the I(V) characteristics are measured with fast pulses because the charge held in deep levels does not have time to change during the pulse.*



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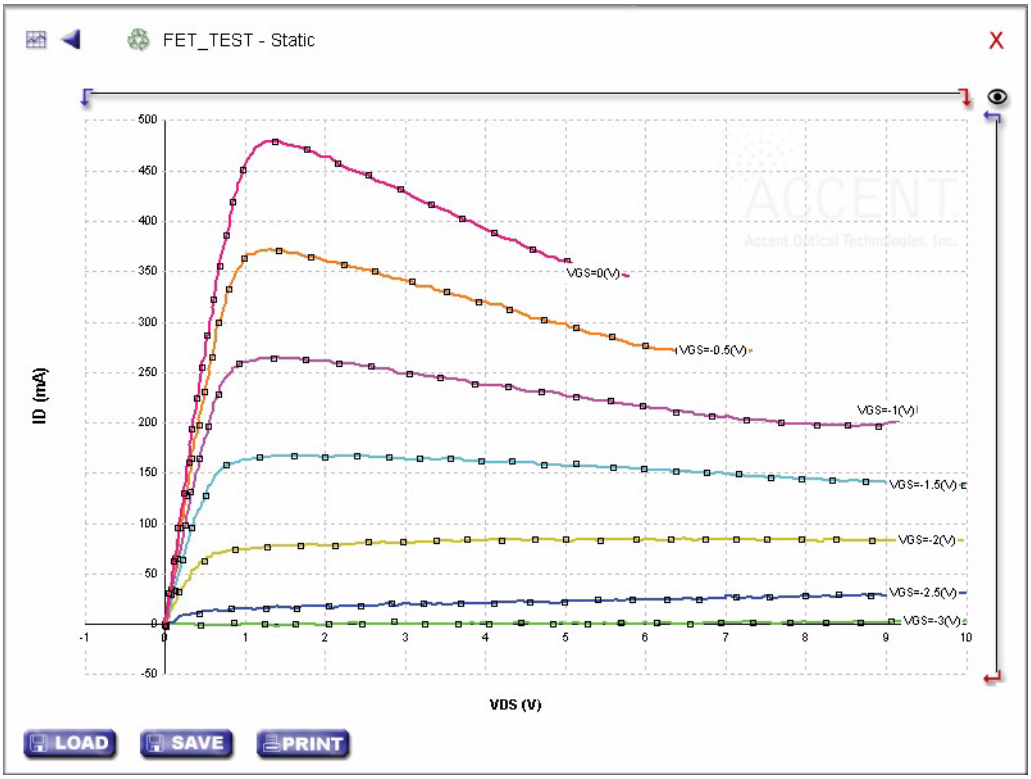


*Figure 4-5: Measurement of Static I(V) characteristics - ID/VDS graph*



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# 4.5 Measuring dynamic characteristics

Return to the main screen and choose Dynamic I(V) as follows:

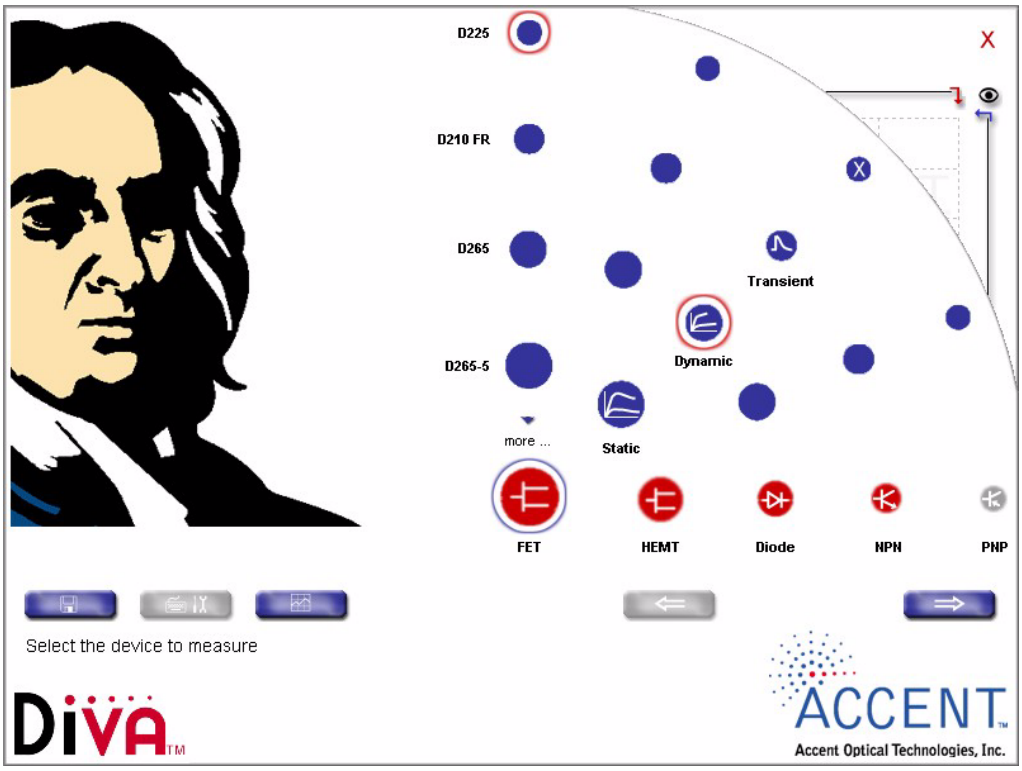


*Figure 4-6: Starting a Dynamic I(V) measurement*

In the measurement set-up screen, values for the following quantities will have been remembered from the set-up window for the static measurement (the last values entered):

VGS
Max VDS
Max ID
Max power
Averaging samples

For this exercise enter measurement values as shown in Figure 4-7. New parameters are described in the following paragraphs.

Bias point

This is the bias point about which the dynamic characteristics are to be measured. It can be anywhere in the ($V_{DS}$, $V_{GS}$) range of values that does not destroy the device, including values of $V_{GS}$ which are not an integer multiple of an available $V_{GS}$ step option. For the purposes of illustration, a bias point appropriate to a class AB amplifier is assumed for this exercise.
Set the VDS value to 3 and the VGS value to -2.

VDS step size

The number is not critical and is decided by how smooth the displayed curves need to be. The graphing routines in DiVA simply connect the measured points with



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straight-line segments, so the density of points in $V_{DS}$ affects the apparent smoothness of the measured curves. 0.1V is a reasonable value to select.

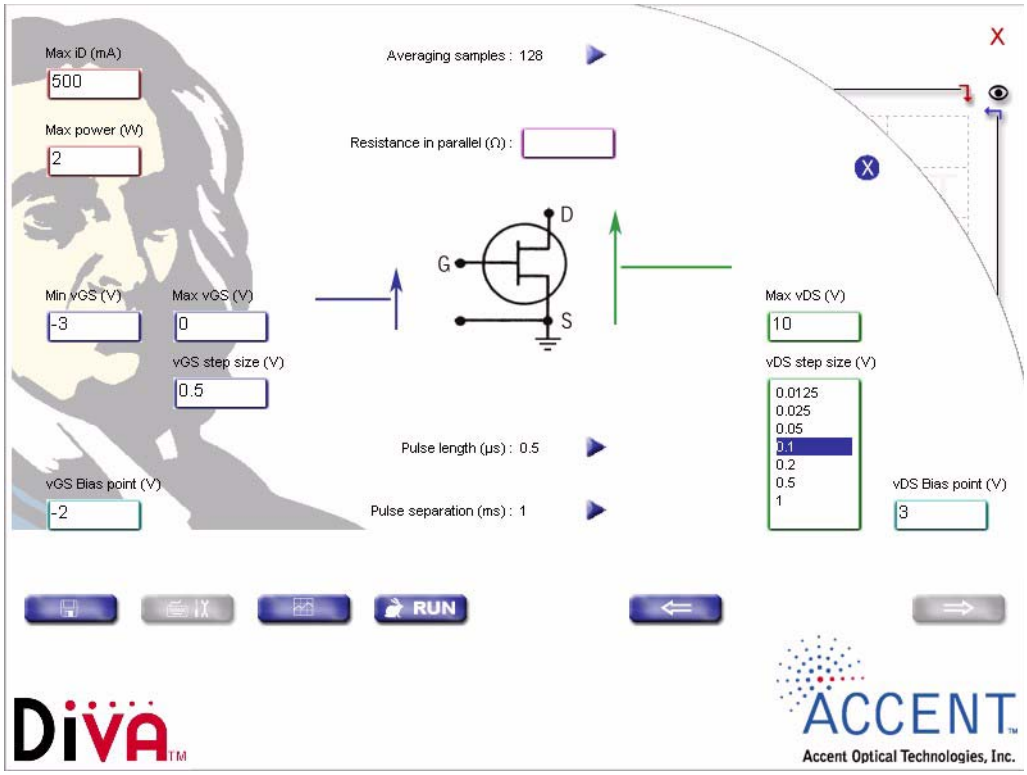


*Figure 4-7: Dynamic I(V) measurement parameters*

Pulse shape

Pulse lengths from 100ns to 1ms are available with pulse separations of 0.5ms to 1s. Such a diverse range of combinations allows the rates governing dispersive phenomena to be investigated, with self-heating either eliminated completely (by making the gap between pulses very large compared with the pulse length) or with self-heating deliberately occurring (by making the gap between pulses of the same order as the pulse length itself).

For the purposes of illustration set:

Length to 0.5µs (500ns)

Separation to 1ms

Graphs for pulse lengths of less than 1µs are not consistent because measurement of the gate nodal (or terminal) current (the "ig" current) is not dependable. For pulses shorter than 1µs, there is distortion of the gate current owing to intentional inductive loading of the "Gate or Base" channel as an oscillation-inhibiting measure. As the branch currents ids, igs and idg are calculated from the measured terminal currents id and ig, if the ig is not dependable then neither are the branch currents. *Hence, if measurement of the gate current is required, pulse lengths of at least 1µs must be used.*



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Click on to start the measurement. For the GaAs MESFET used in this exercise, the result is as follows:

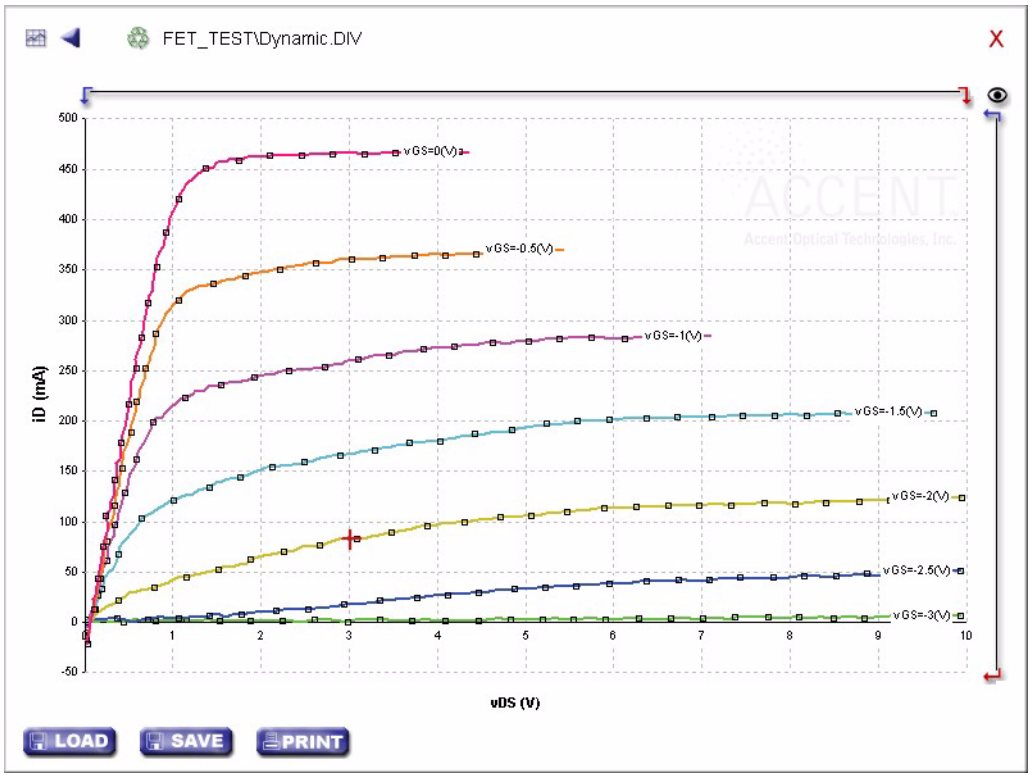


*Figure 4-8: Measurement of Dynamic characteristics*

To display both the Static and Dynamic curves on the same graph:

1. Click on to display the graph options dialog box (see Section 3.7.1).
2. Select the compare graphs tab then select the static graph.
3. If necessary change the display settings for the graph so that it is easy to differentiate between the two.

The result is illustrated in Figure 4-9.

*Observe the dramatic difference between the Static curve set and the Dynamic-measured set of characteristics (which are equivalent to the large-signal RF set the device will follow when used as a class AB amplifier about the chosen bias point), thereby hinting at the serious design errors that would be built into a circuit design if the Static characteristics were used.*

*The two curve sets should intersect at the bias point providing a slow enough sweep has been used for measuring the static curves and providing also the device temperature has not changed due to external heating or cooling between making the two types of measurement.*



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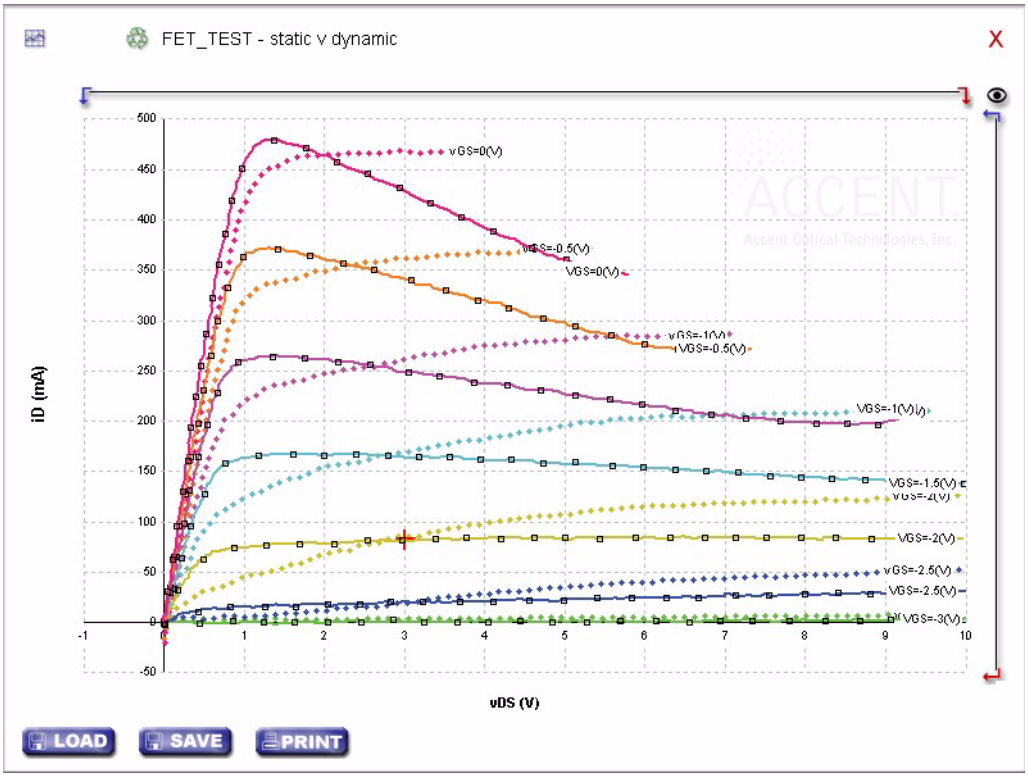


*Figure 4-9: Comparison of Static and Dynamic characteristics*

## 4.6 Conclusion

The foregoing example has exercised all the important features of the DiVA interface required to make static (dc) and dynamic (pulsed) *I(V)* measurements on a FET or HEMT. Making measurements on bipolars or diodes is very similar.

## 4.7 Viewing Past Results

Past results may be viewed using the LOAD

option in the SHOW GRAPH menu. Refer to Section 3.7 for details.

**NOTE**

*Remember that when more than one graph is loaded, an arrow will appear between the Graph Options* *and Throw Away* *icons to enable selection of the graph to be displayed.*



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# Chapter 5: Running DiVA from LabView or other External Software

## 5.1 Introduction

The DiVA software may be run in a command-line or batch mode, allowing the DiVA instrument to be controlled by other programs. These notes refer exclusively to LabView but Section 5.4 and onwards may be applied to the running of DiVA from any external software package. The notes are not a guide to programming with LabView.

The job of running DiVA from LabView can be split into two tasks. The first task is to program LabView to send a command or commands to the DiVA software. The second task is to determine which commands should be sent to make DiVA perform the desired measurements. Both tasks are described in these notes.

## 5.2 Programming LabView to run DiVA

To represent DiVA in LabView, what is referred to as a virtual instrument must be set up. Fortunately, LabView has a library of virtual instrument templates, which will perform predefined functions. The virtual instrument is customised by providing parameters to the function in a similar manner to the passing of parameters to library functions in traditional programming environments.

The LabView function that can be used to talk to DiVA is called “Exec” and is found in the Communications sub-palette of the Functions palette. In the next section there is a step-by-step guide to setting up an Exec box to perform a DiVA measurement.

**NOTE**

*A single Exec box can perform a range of measurements on a single device. To measure multiple devices, multiple calls to Exec boxes are required. To simplify the separation of the measured data files for multiple devices it is best to have a separate Exec box for each device to be measured. Where this approach is not practical, for example in a program designed to perform the same measurements on hundreds of devices on a wafer, the LabView program will need to copy or rename the output files generated between each call to the single Exec box.*



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# 5.3 Setting up an Exec box

Perform the following steps to set up an Exec box to make DiVA measurements:

1. Select NEW VI (Virtual Instrument). Two windows should appear - one of which has “Diagram” in the title bar. Select EDIT, SELECT PALETTE SET and DEFAULT to obtain the Functions Palette (see Figure 5-1).

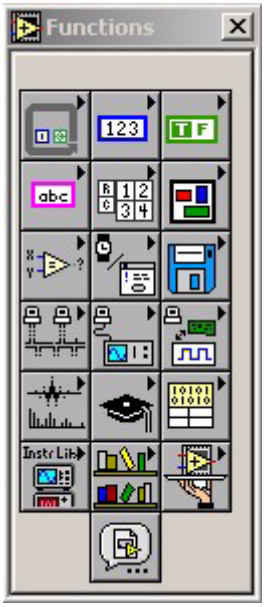


*Figure 5-1: LabView Functions Palette*

2. Select the Communication button from the Functions palette to display the Communications sub-palette (see Figure 5-2).

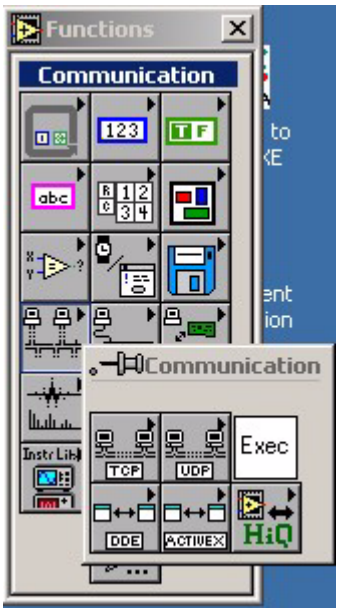


*Figure 5-2: LabView Communications sub-palette*



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3. Select the Exec button

from the Communication sub-palette; the cursor turns to a hand and the Exec item can be dragged and placed in the Diagram window (see Figure 5-3).

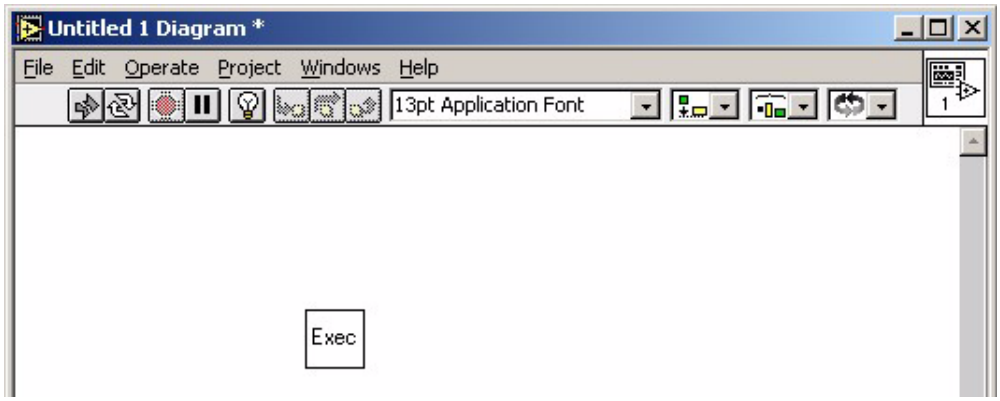


*Figure 5-3: LabView Exec item in Diagram window*

4. Right click on the Exec box and select OPEN FRONT PANEL in the drop down menu to display the Front Panel Window for the Exec box (see Figure 5-4).

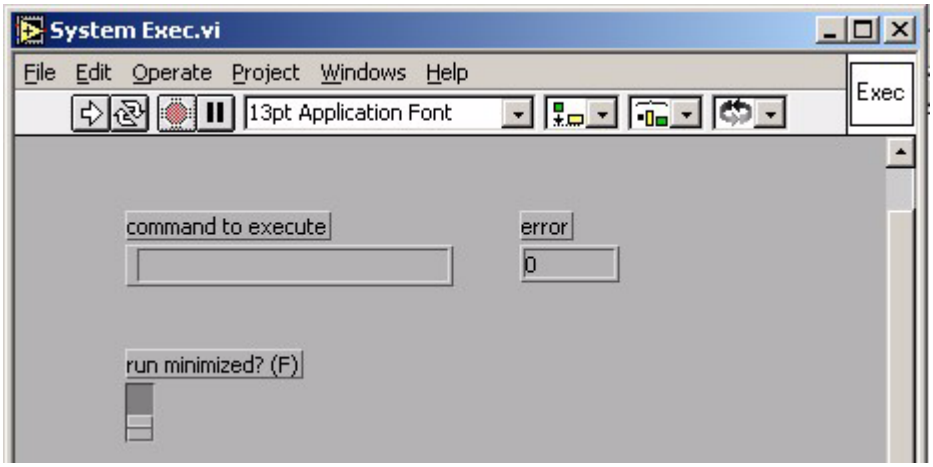


*Figure 5-4: LabView Exec - Front Panel window*

5. The only field of interest is “command to execute”, the other two should be ignored. The “command to execute” box is a text entry box. Click in the box. A button labelled “enter” will appear on the left hand end of the menu bar and a text entry cursor will start flashing in the entry box (see Figure 5-5).

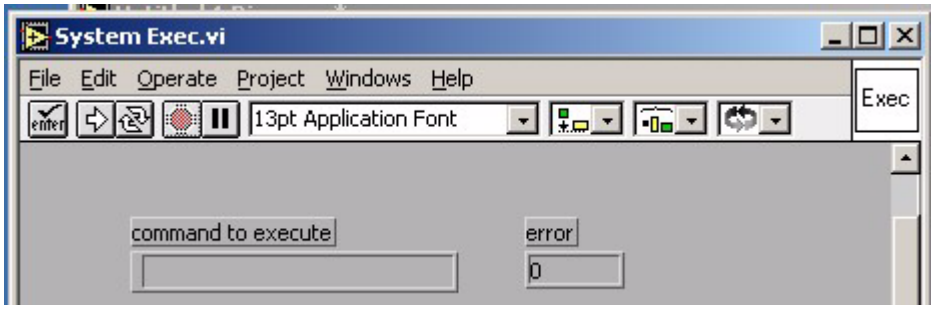


*Figure 5-5: LabView - command to execute*



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6. At this stage the command to run DiVA could be entered directly, but the text entry box is very small so only a portion of the command can be viewed. It is easier to set up the desired command in a text editor first and then use cut and paste to place it in the command to execute entry box. This latter approach will be assumed for the rest of these instructions.

   Create and enter the text as follows:

   a. Use Notepad or another text editor to type a line of text giving three items of information (see also Figure 5-6):

      [Full path of AutoRunner.exe] –auto [Full path of .dar file enclosed in “”]

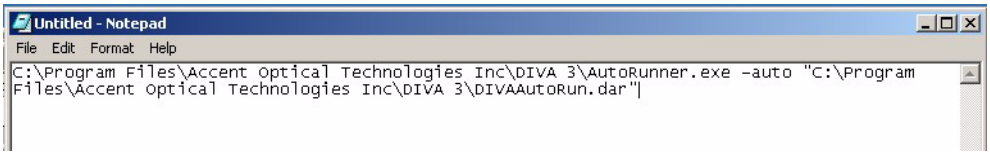
Untitled - Notepad
File Edit Format Help
C:\Program Files\Accent Optical Technologies Inc\DIVA 3\AutoRunner.exe -auto "C:\Program Files\Accent Optical Technologies Inc\DIVA 3\DIVAAutoRun.dar"

*Figure 5-6: Labview - Create ‘command to execute’ in Notepad*

      Here the full path of the DIVA 3 executable is
      C:\Program Files\Accent Optical Technologies Inc\DIVA 3\AutoRunner.exe
      and the full path of the automation file (.dar file) is
      “C:\Program Files\Accent Optical Technologies Inc\DIVA 3\
      DIVAAutoRun.dar”

      Note the use of inverted commas.

   b. When satisfied that the command line is correctly entered in Notepad, select all the text and cut or copy it.

   c. Return to the Exec Front Panel window and click in the “command to execute” box

   d. Paste the Notepad data into the command line. As the text box is small only the end of the line will be visible.

7. The Exec block may be tested by selecting the Run button from the menu bar.

## 5.4 The .dar file

The commands to run DiVA automatically are simply the name of ASCII files. There are two types of ASCII files, the one defining the measurements to be made and the second defining where the measured data should be placed.

The names of these ASCII files are collected into a single ASCII file, which is given the extension “.dar” (DiVA Auto Runner). Each line of the “.dar” file should consist of the name of a measurement (project) file followed by the name of the file to which the measured results should be written.

The two names must be separated by a space.



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**NOTE**

*It is important that the names of the files contain the full path and are enclosed in inverted commas. If inverted commas are not used then spaces in the file name or path may be misinterpreted as the end of the file name.*

The DIVA 3 software will generate a ".dar" file for you in interactive mode (see Section 3.6.3), though this feature is designed for the immediate running of a series of automatic measurements.

### 5.4.1 Project Files

The ASCII file type that defines the measurements to be made is referred to as a project file and has the extension ".pul". The project files are best generated by using the DiVA software in interactive mode. Define the measurement to be made in the DiVA interface and the associated project file will be saved automatically.

Project files from earlier versions of DiVA may also be used.

As DiVA project files are ASCII files, they may be edited using a text editor. Text editing may be quicker where a lot of similar measurements are to be set-up. (Create a project file using DiVA, make multiple copies and edit one or two parameters in each copy.)

### 5.4.2 Measurement files

Each measurement run of DiVA generates a data file with the extension .div.

The name of the measurement file should be entered into the ".dar" file, for example "C:\DIVA\results\pulse_measurement1.div".

## 5.5 Summary

In summary, to set-up a series of measurements first define them as project files using the DiVA interface. Collect the names (and paths) of the project files together with file names for output into a single ASCII file with the ".dar" extension.

Then set up an Exec box in LabView and use the "command to execute" box to pass the name of the ".dar" file to the DiVA software.

The Exec box can then be combined with other elements of LabView (including other Exec boxes) to make automated measurements, move a prober between samples and analyse results.

A document, in pdf format, is provided with the DiVA software giving details of the project file format and of potential errors that may be returned by the instrument when run in automation mode.



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# Chapter 6: Error Conditions

## 6.1 Introduction

Error messages are written to the screen of the controlling computer when exceptional states or conditions arise within the instrument.

The messages are self-explanatory and indicate what action should be taken to rectify the fault. In cases where that is not so, the action which should be taken is indicated in the following list.

If third party software is used to run DiVA automatically, only the error number is passed from DiVA and this must be identified appropriately by the software in use. Guidance for running DiVA from LabView is given in Chapter 5.

## 6.2 Messages

| Error Number | Message and Cause |
|---|---|
| 1 | ERROR_BIAS_EXCESSIVE<br>The bias you have requested requires an output voltage higher than the instrument can generate. |
| 2 | ERROR_BIAS_CURRENT_EXCEEDS_LIMIT<br>The current through the device at the bias point requested exceeds the current limit you have set. |
| 3 | ERROR_BIAS_POWER_EXCEEDS_LIMIT<br>The power dissipation in the device at the bias point requested exceeds the power limit you have set. |
| 4 | ERROR_GATE_OR_BASE_BIAS_EXCESSIVE<br>The dc base current at the bias point you have requested is higher than the instrument can generate.<br>or<br>The device is passing so much gate current that the VGS bias you have requested requires an output voltage higher than the instrument can generate. |



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| Error Number | Message and Cause |
|---|---|
| 5 | ERROR_GATE_OR_BASE_EXCESSIVE<br>Iteration failure: one or more of the base current values requested is greater than the instrument can supply.<br>or<br>The device is passing so much gate current that one or more of the VGS values you have requested requires an output voltage higher than the instrument can generate. |
| 6 | ERROR_COLLECTOR_OR_DRAIN_EXCESSIVE<br>Iteration failure: at one or more of the pulsed base currents requested, the collector current exceeds the limit set.<br>or<br>The device is passing so much drain current that one or more of the VDS values you have requested requires an output voltage higher than the instrument can generate. |
| 7 | ERROR_POWER_EXCEEDS_LIMIT<br>Iteration failure: at one or more of the pulsed base currents requested, the instantaneous power dissipation in the device exceeds the limit set.<br>or<br>The power dissipation in the device at one or more points along the transient exceeds the power limit set. |
| 8 | ERROR_CURRENT_EXCEEDS_LIMIT<br>The current through the device at one or more points along the transient exceeds the current limit set. |
| 9 | ERROR_ITERATION_TIMEOUT<br>Iteration failure: one or more of the pulsed base currents requested cannot be found. |
| 15 | ERROR_SAFETY_INTERLOCK<br>Measurements have been stopped because the safety interlock has been activated. |
| 16 | ERROR_BAD_PROJECT_FILE<br>Sorry, this file format cannot currently be read by this version of DiVA. |
| 17 | ERROR_DEVICE_NOT_SUPPORTED<br>The file cannot be loaded. The current hardware does not support testing of this device. |
| 18 | ERROR_NO_DIVA<br>No DiVA instrument responded. Please check the machine is connected and powered and reset if necessary. |



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# Appendix A: Additional Examples

This chapter contains examples of other uses of the DiVA instrument. The coverage is illustrative rather than exhaustive.



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# A.1 Example 1 - comparing GaAs FET characteristics with different bias points

This example is used to illustrate the difference between dynamic GaAs FET characteristics measured about different bias points.

**Background**
From the example of Chapter 4, some devices evidently exhibit a current-voltage relationship which is governed by the time-dependent character of the voltages applied. In this example we illustrate the dependence of the fast-pulse measured characteristics upon the starting bias point.

**Set-up**

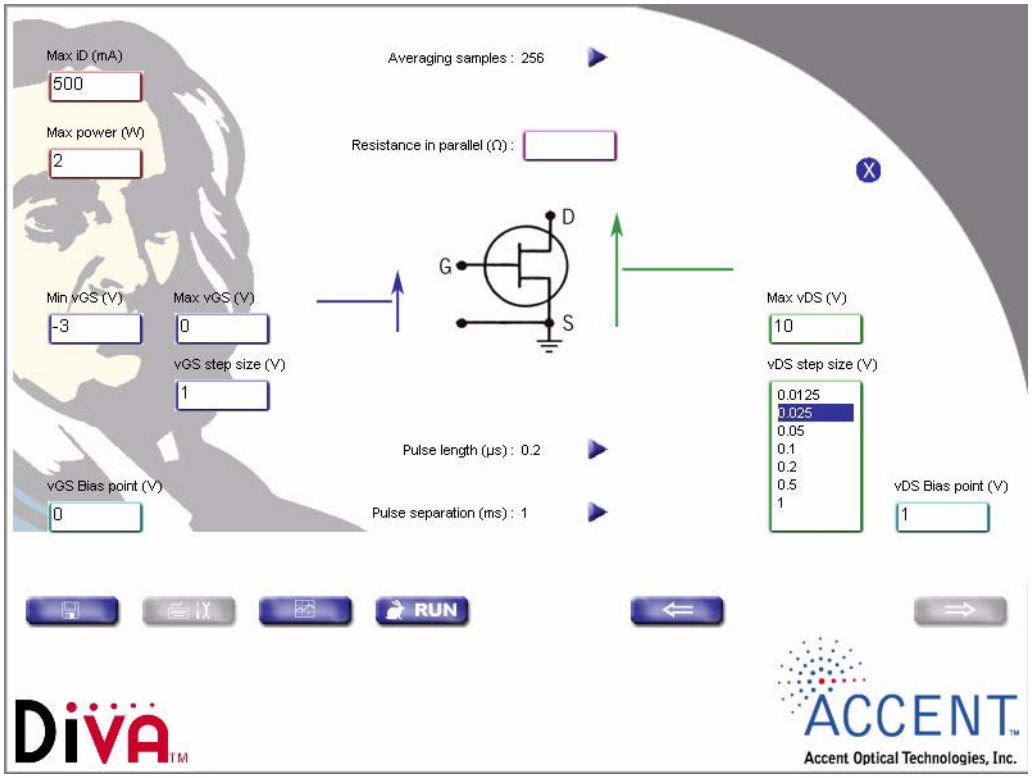


*Figure A-1: Example 1 - Set-up screens for measurement about first bias point*

Figure A-1 shows the set-up screen for the measurement about the first bias point, as might be appropriate to a biased mixer circuit. A pulse length of 100ns (the shortest the instrument will allow) has been set to try and ensure a fast enough measurement for no effects of dispersion to occur.

Once the set of *I(V)* measurements at the first bias point has been acquired and displayed, select to keep the graph displayed then change the bias point parameters for the second measurement as follows:



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A bias point appropriate to a class B amplifier will be assumed, so
$V_{DS}$ Bias point = 8V, $V_{GS}$ Bias point = -3V

Results

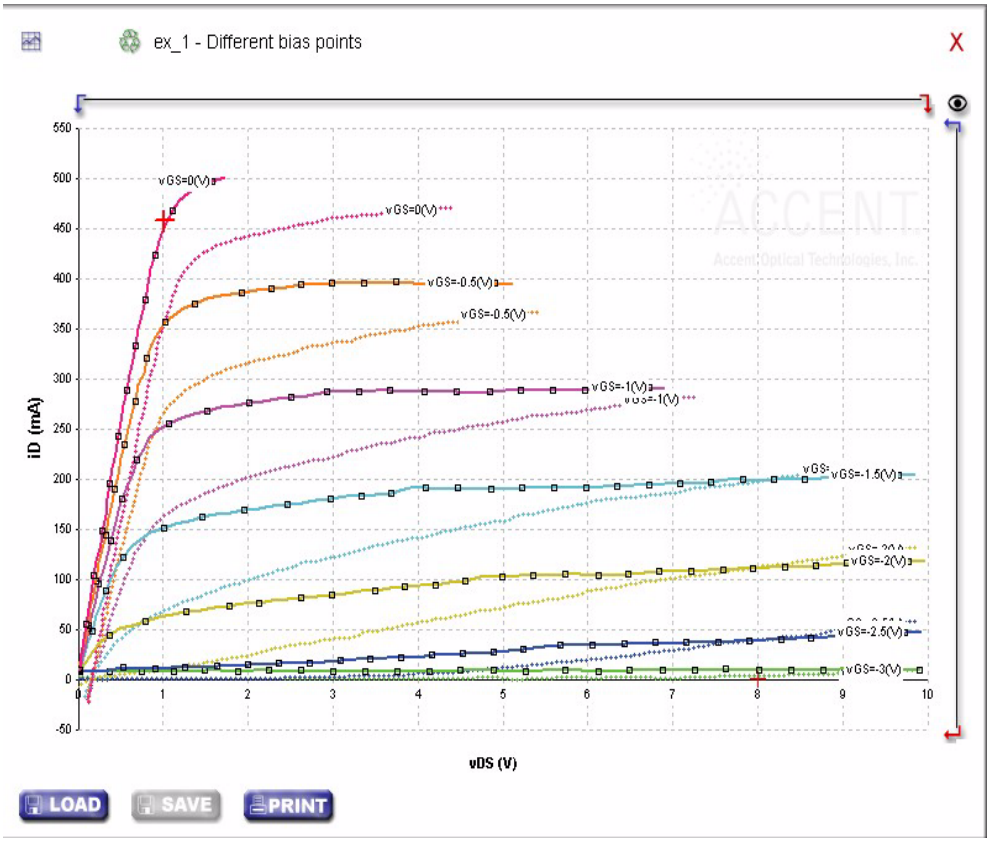


*Figure A-2: Example 1 - Graph of measurement about different bias points*

**Conclusion**
Not all devices exhibit such a pronounced difference between the dynamic characteristics measured about different bias points as the FET in this example. Many do, however.

When devices which are as dispersive as the foregoing example are built into real circuits, care must be exercised at the design stage to ensure that a set of large-signal RF *I(V)* characteristics appropriate to the application is used. For instance, if a set of dynamic *I(V)* characteristics has been measured for the design of a power amplifier operating in class B, that set of characteristics may be much in error for the design of mixers or RF switches. Both mixers and switches use low $V_{DS}$ bias (or no $V_{DS}$ bias) and, as the example shows, the large-signal characteristics measured about such low $V_{DS}$ bias points can be very different from those measured at higher $V_{DS}$.

The message is that the large-signal RF (or dynamic) characteristics must be determined about a bias point close to that for the practical circuit in which the device is to be used.



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# A.2 Example 2 - static characteristics vs sweep rate

This example is used to demonstrate how the static characteristics of a device may depend upon the sweep rate used to measure them.

**Background**
A true measurement of the static characteristics relies on the internal temperature of the device being steady before making the measurement, allowing plenty of time for the temperature to rise and become stable after the application of the voltages.

In the instrument it is convenient to generate the drain voltage as a staircase of steps and, imagining a smooth line drawn through the staircase, to express the rate of rise of $V_{DS}$ as a sweep of, say 0.1V/s.

To measure the static characteristics, the rate at which $V_{DS}$ is applied - the sweep rate - must be slow enough for the device to come to a steady-state temperature at each step of $V_{DS}$. In most devices, 0.1V/s is slow enough for this criterion to be satisfied. If, on the other hand, the sweep rate is made much faster, say 10V/s, there may not be sufficient time at each step of $V_{DS}$ for the internal temperature to reach a stable value consistent with that magnitude of $V_{DS}$. Under these conditions, therefore, the current-voltage characteristics will be different from the true static case.

Useful information can be inferred from these differences concerning the effect self-heating has on the device characteristics compared with charge exchange with deep levels. Generally, the so-called thermal time constant might be several hundred microseconds to several seconds: at 10V/s sweep rate, $V_{DS}$ changes by 1mV in 100µs, and by 0.1V in 10ms. Assuming the deep level (or trapping) time constant to be less than the thermal time constant, for voltage increments of these magnitudes occurring over these time intervals we can expect the charge held in traps to have time enough to reach a steady state, but the device temperature not to have attained a steady state. Caution is necessary, however, because sometimes the thermal time constant and the characteristic time for trapping may be comparable.

**Set-up**

Figure A-3 shows the set-up for the measurement at the first sweep rate.

Once the set of *I(V)* measurements for the first sweep rate has been acquired and displayed, select to keep the graph displayed then change the sweep rate to "10V/s".

**Results**
Figure A-4 shows the results, in which the lowermost set of curves stem from the slowest sweep measurement (0.1V/s): these are the set which are the near-enough "true" static set. The results show an interesting feature of this particular FET, aside from the difference in the characteristics as a function of $V_{DS}$ sweep rate. This feature is the "curl-back" of the curves evident for $V_{GS}$ = 0V, -0.5V and –1V for the slowest sweep rate. "Curl-back" is due to impact ionization occurring at the high internal temperature at which the chip is working in these regions. The effect is repeatable and the device sustains it without damage – this is robust technology!



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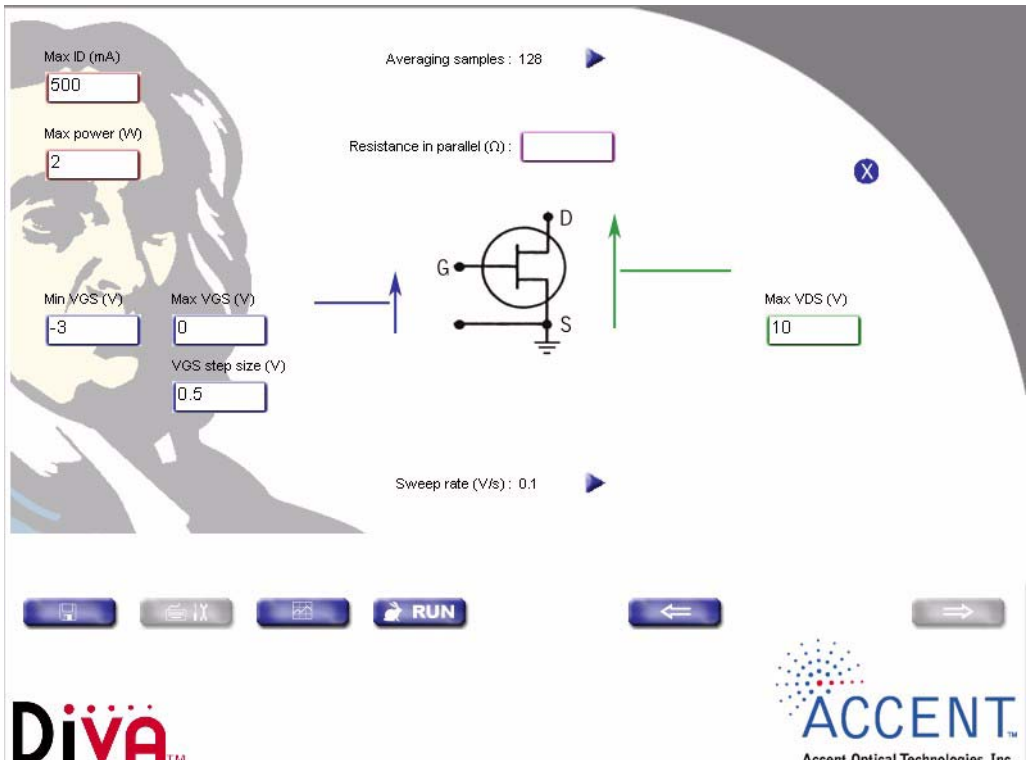


*Figure A-3: Example 2 - Set-up for measurement at first sweep rate*

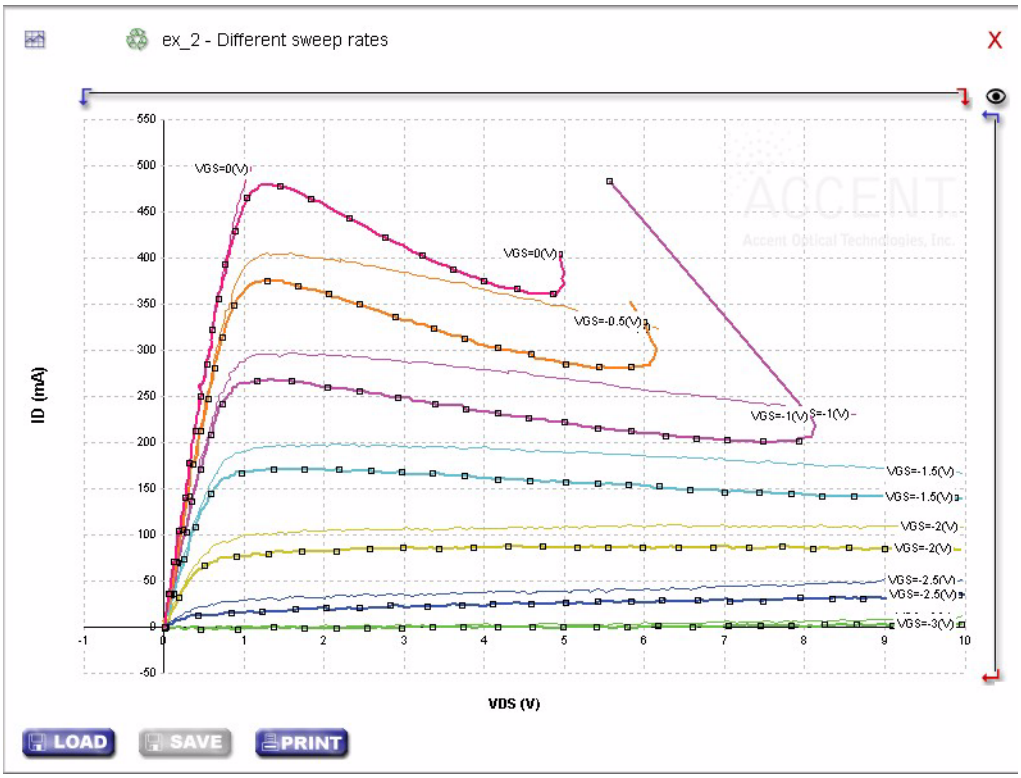


*Figure A-4: Example 2 - Measurement graphs from different sweep rates*

**Conclusion**

Don't rush! Do not set the highest sweep rate in the belief that this is the quickest way to measure the static characteristics of a device: if you do, you may not be measuring what you want to measure !



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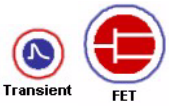
# A.3 Example 3 - appreciation of the time constants involved in device dispersion (Short Transient)

This example is used to gain an appreciation of the time constants involved in device dispersion (i.e. the rate at which the characteristics measured with the fastest pulses relax to the long-term steady-state (static) characteristics).

**Background**
Referring to Figure 4-9, if the length of the pulses used to measure the dynamic set of characteristics were gradually increased from the 500ns used there to, say, several tens of seconds (although the instrument does not go that far), the dynamic characteristics would gradually change from those shown as the dynamic set on Figure 4-9 to those which are the static set. The dispersion time constant may vary with position on the *I(V)* plane - notably whereabouts the device is biased.

In many devices there are multiple time constants acting. Typically, dispersion arising from deep levels or surface states acts on a timescale of microseconds, whereas changes in the *I(V)* characteristics due to self-heating may require seconds to stabilize depending upon the chip thickness, the package into which it is bonded, and exterior heat sinking. Currently the DiVA measures and displays transients in the drain current of HEMTs, FETs and bipolars (D225HR and D225FR instruments only), up to 1msec (short transients) only. No instruments display currents as a function of time in diodes, or long transients.

**Set-up** 

A GaAs FET of the same general type as that in Chapter 4 is used for this example. With a project name "ex_3" and the type of measurement as short transient, enter values as shown in Figure A-5.

Leave the fields VDS and VGS blank where, or if, no further transient measurement is required.

Measurement of current transients may take several minutes and, in some cases, up to 15 minutes. Please be patient. If there is a fault or if the measurement conditions in the set-up cannot be attained the instrument normally issues a warning within the first minute or so of trying to start that particular measurement.

**Results**
The measured short transient is shown in Figure A-6. In this particular GaAs FET the transient

- almost certainly arises from surface states;
- does not account for the entire difference between the values of the instantaneous dynamic value of $i_D$ and the long-term steady-state (or static) value, $I_D$: there is at least one other important transient operating on a timescale much greater than the 1msec analyzed by the instrument.



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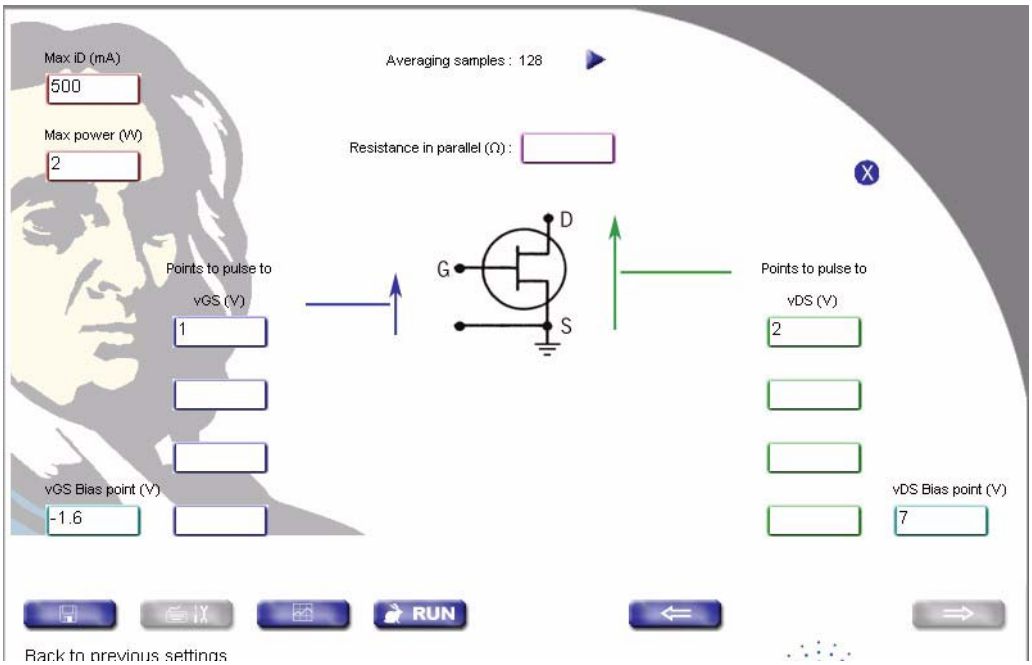


*Figure A-5: Example 3 - Set-up for short transient measurement*

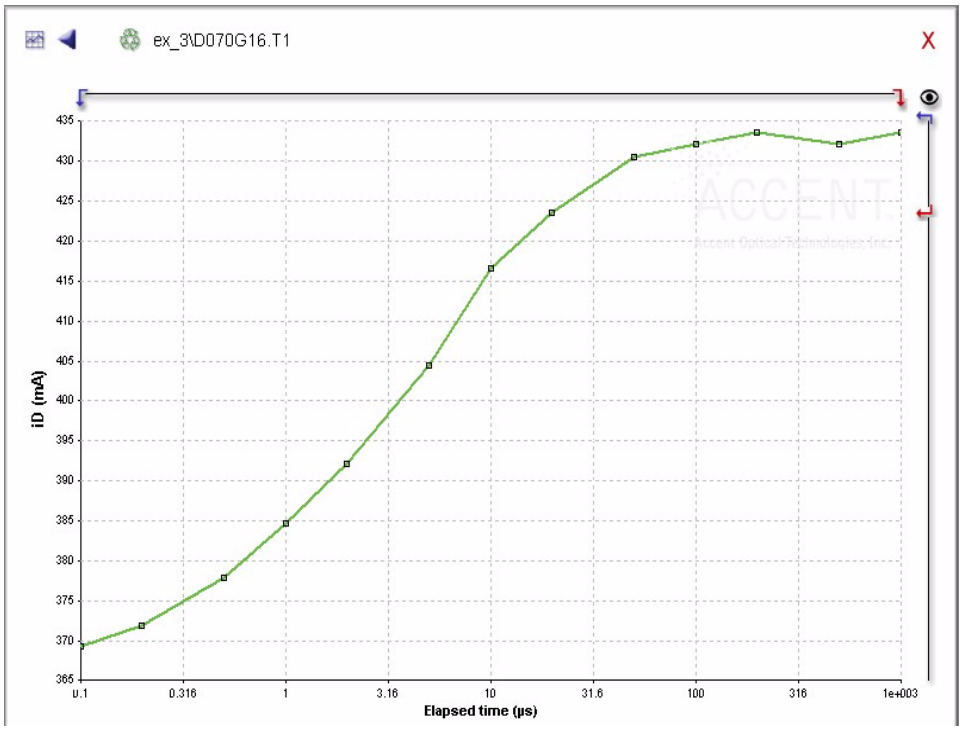


*Figure A-6: Example 3 - Measured short transient*

**Consequence**

In the design and analysis of circuits in which the bias is pulsed on just before the RF signal is applied it may be important to incorporate into a large-signal model the time transition between the instantaneous large-signal RF characteristics and the long-term steady (or static) characteristics. Dispersion transients may last for a time of typically several hundred microseconds, which is comparable with the duration of a pulsed phased-array radar transmission and with the length of the timeslot in a GSM mobile telephone handset (which is 577µs).



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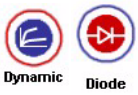
# A.4 Example 4 - measuring current-voltage characteristics of the gate-source “diode”

This example illustrates the measurement of the current-voltage characteristics of the gate-source "diode" of a FET or HEMT for inclusion in some commonplace large-signal models.

**Background**
When the gate of a FET or HEMT is driven to positive enough voltage, 0.7V to 0.8V typically, the device starts to pass conduction current between the gate and the source: the gate-source part of the device behaves somewhat like a diode. Some large-signal models use a circuit topology in which this flow of gate current is represented by a diode element whose characteristics, therefore, must be ascertained for inclusion in the model.

The use of a diode element to model gate-source conduction is an approximation. Nevertheless, if some large-signal models require it, it is as well that we are able to measure it.

**Set-up** 

Connect the device to the instrument as shown below.

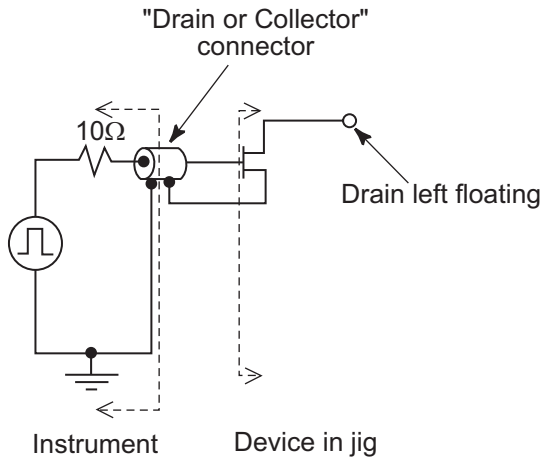



*Figure A-7: Device connection*

With the drain left floating, as in this connection, the question arises as to whether the diode characteristic we are about to measure would be different if the drain were connected to the source. The answer is that, since the gate forward current is determined by the gate contact area, near-enough the same diode *I(V)* characteristic would be measured in both cases. There is a difference arising from the different nett series resistance in the two cases (it is lower when the drain is connected to the source), but the effect is small until the forward voltage applied becomes large enough for the forward characteristic to become dominated by the series resistance rather than the Schottky barrier itself.

Figure A-8 shows the set-up for this example.



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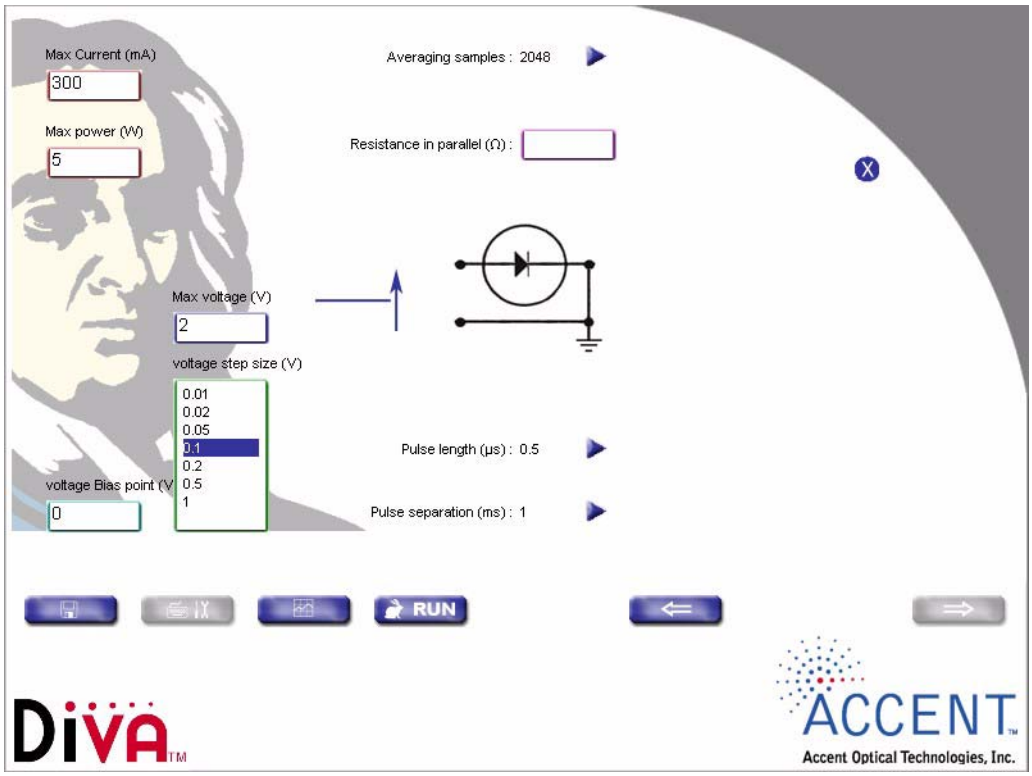


*Figure A-8: Example 4 - Set-up for a gate-source “diode”*

**Results**

Figure A-9 shows the measured gate-source conduction current characteristic.

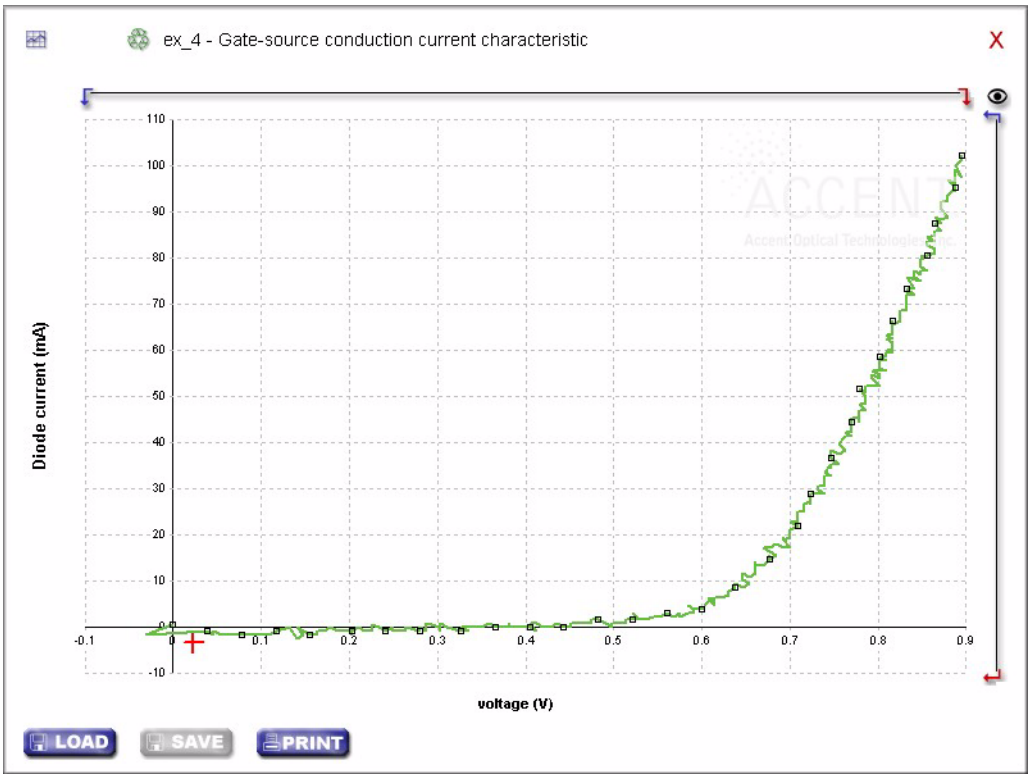


*Figure A-9: Example 4 - Measured gate-source conduction current characteristic*



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**Conclusion**

A diode equation can be fitted to the foregoing measurements where required for inclusion in large-signal FET and HEMT models. Although many large-signal models represent gate conduction in this way, such a representation assumes the diode passes a current which is a function only of the voltage across it, whereas the gate-source conduction current in a real device actually depends upon the gate-drain voltage as well. Given that the correspondence between practical circuit behaviour and the predictions of non-linear simulators is generally variable, it is difficult to say how serious (or otherwise) the approximation is.

**NOTE**

*Diode measurements on various instrument versions*
*The D210 instruments have dual-polarity output, covering the voltage range -10V to +10V. On this instrument, forward and reverse characteristics of diodes can be measured in one go. The 25V and 65V instruments are single polarity. Hence, to measure the forward- and reverse characteristics the diode must be physically reversed.*



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# A.5 Example 5 - dynamic characteristics for a bipolar transistor

This example is used to illustrate the measurement of a set of dynamic characteristics for a bipolar transistor.

**Background**

The DiVA Applications Manual discusses the conditions which must be satisfied if any transient effects detected by the dynamic-measurement instrument are NOT to be due to the intrinsic frequency limiting processes active within the device. Dynamic measurements can be made (and compared with static characteristics) which conform to this criterion. Nevertheless, the question remains as to what would be measured if fast enough pulses were used to NOT satisfy this criterion. What do the $i_C\,(v_{CE}\,,i_B)$ characteristics look like when they are limited by the intrinsic frequency-limiting processes inherent in the device?

**Set-up**


Using an NPN transistor as an example, Figure A-10 shows the set-up for a dynamic measurement using pulses of sufficient duration to avoid the intrinsic frequency limitation. The bias point has been chosen arbitrarily.

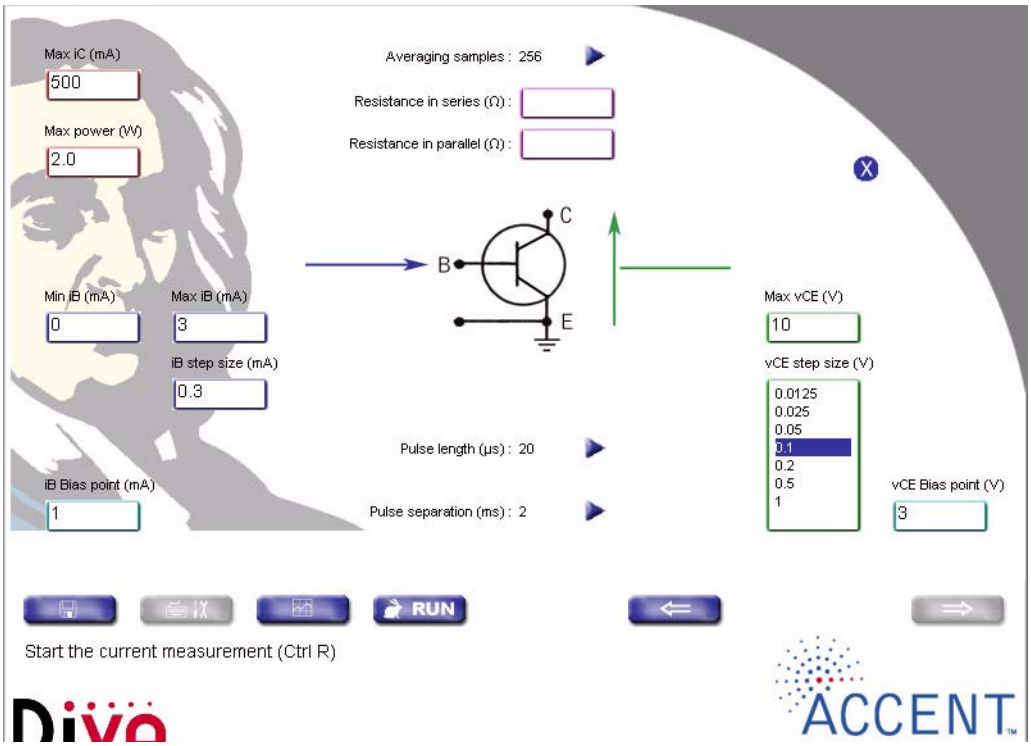


*Figure A-10: Example 5 - Set-up to measure a bipolar transistor*

Setup and measure also the static characteristics at 1 V/S sweep.

To examine the effect of intrinsic frequency-limiting processes upon the $i_C\,(v_{CE}\,,i_B)$ characteristics, the only change necessary to the set-up of Figure A-10 is to reduce the pulse length. For the present device, a pulse length of 0.1µs illustrates the point.



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**Results**

Figure A-11 shows the result for the "long pulse" (20µs) measured characteristics. Note that the cross marking the bias point falls in the gap between two characteristics curves because the instrument has not been set-up to measure a curve at the bias point set ($I_B$ = 1mA). Nevertheless, the instrument recognizes the bias condition requested and biases the transistor at the correct point independently of the constant $I_B$ or $i_B$ curves set-up to be measured.

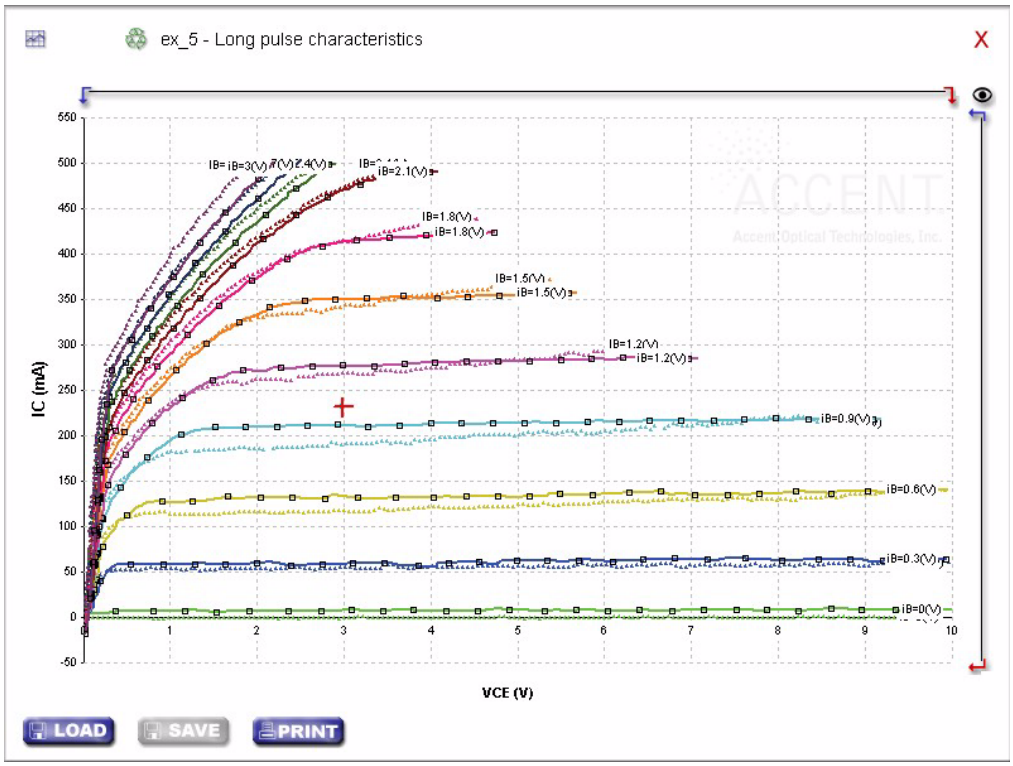


*Figure A-11: Example 5 - Graph of 'long pulse' (20µs) measured characteristics*

There is a difference between the dynamic characteristics and the static characteristics: in the current-saturated regime, the dynamic set are flatter at the larger currents. Although the pulse is long enough for the result not to be affected by intrinsic frequency limitations, the mark:space ratio is small enough for heating to be determined by the dc dissipation (i.e. not dependent upon the ($v_{CE}$, $i_C$) operating point). At dc the transistor becomes hot at the larger currents, and self-heating causes the current to increase.

Figure A-12 shows the "short pulse" (0.1µs) measured characteristics which, by comparison, have much lower current gain and much higher output conductance. Additional trials will show that these "short pulse" measured characteristics are sensitively dependent upon the bias point.



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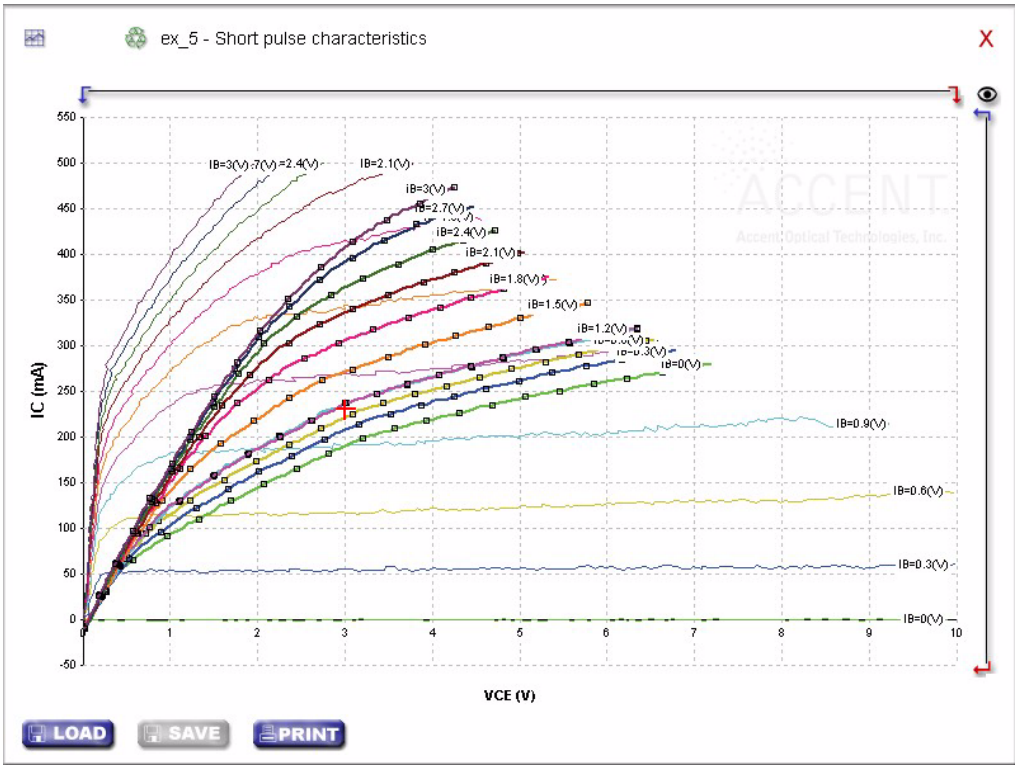


*Figure A-12: Example 5 - Graph of 'short pulse' (0.1µs) measured characteristic compared with'long pulse' (20µs)*

**Conclusions**

1. The example serves as a graphic illustration of what will happen if care is not taken to measure the device characteristics at low enough frequencies (i.e. long enough pulse lengths) to be outside the intrinsic frequency limit if the intention is to be outside that limit.
2. If the device is to be used within the band where it is limited by, or begins to be limited by, intrinsic frequency-limiting processes then the instrument can be used to find the set of current-voltage characteristics along which the device will work at the chosen frequency, and at the chosen bias point.
3. In this regime, the $i_C(v_{CE}, i_B)$ characteristics are extremely dependent upon the bias point. The output conductance becomes progressively higher the higher the collector current at the bias point. An easy way to visualize what the $i_C(v_{CE}, i_B)$ characteristics look like in these circumstances is to imagine a straight line drawn from the origin to the bias point and then to imagine a "fan" of curves spreading out from the origin around the straight line such that the spacing between the individual curves becomes larger the longer the pulse length.

Bipolar transistors, including heterojunction bipolar transistors (HBTs) can exhibit behaviour which at first sight is curious. One observation is that, for fast pulses, the measured *I(V)* curves may look correct except for the $i_B = 0$ curve which, instead of producing $i_C = 0$, gives a finite value of collector current i.e. larger than $i_{CE0}$. Recombination of the minority carrier charge injected into the base may be a relatively slow process in some device types, and may be slow compared with the shortest pulses with which the instrument measures *I(V)* characteristics. The collector current will not have decayed away (to $i_{CE0}$) when the instrument samples the current at the prescribed pulse time.



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# A.6 Example 6 - Measurements made on high- and low-resolution

Depending upon whether the maximum current permitted during a measurement is set in the DiVA interface at less than a critical value, or more than the critical value, the measurements will be performed at high resolution of the drain (or collector) current, or low resolution of that current. (In D210s and the D225 the critical value is 50mA, in the D225HR and D225FR it is 10mA, while in the D265 it is 250mA.) This example illustrates the differences which result.

**Background**

If the low-current regions (meaning a few tens of milliamps) of a set of *I(V)* characteristics of a relatively high current device (meaning several hundred milliamps) are examined by expanding the graph scale in the area of interest, the curves in the expanded-scale region may appear irregular or “noisy”. The same applies if a low-current device is measured after setting a maximum current in the DiVA interface of many times the current the device will actually pass. Such irregularity in the curves is determined by the resolution with which the drain (or collector) current is sensed. To provide cleaner-looking curves for currents up to (but not including) the critical value, an automatically switched high-resolution mode exists within DiVA.

**Set-up**


A bipolar transistor was measured using a D225 instrument to illustrate the differences typical of low- and high-current resolution measurements. The only change made in the set-up to obtain the two sets of curves is to set ‘Max. IC’ first to 49 mA to produce the high-resolution set of curves, and then to 55mA to produce the low-resolution set.

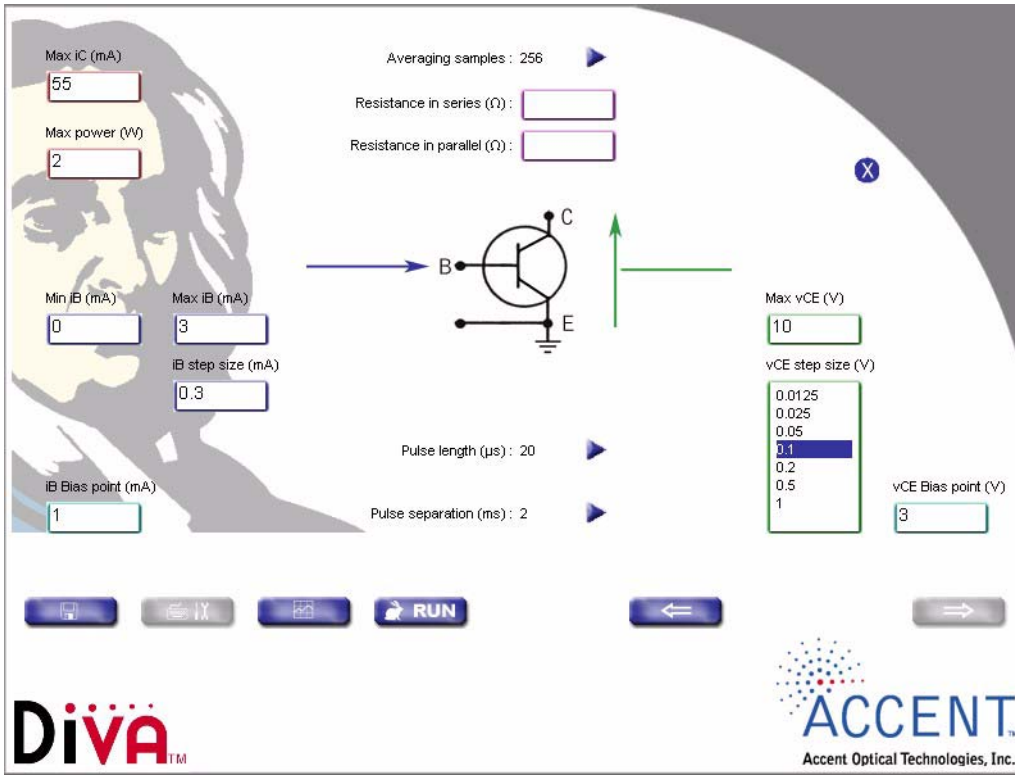


*Figure A-13: Example 6 - Set-up screen for low resolution*



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**Results**

Figure A-14 and Figure A-15 show the results. When the maximum current permitted in the measurement is less than 50mA, noticeably cleaner curves are obtained.

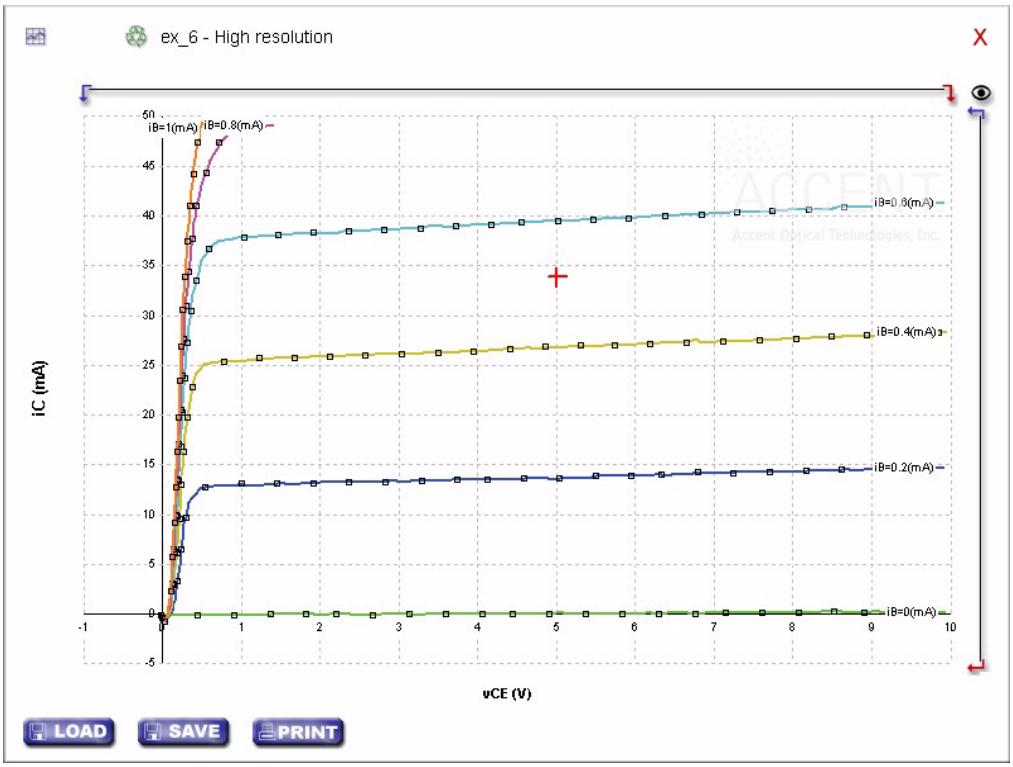


*Figure A-14: Curves produced from measurements at high resolution*

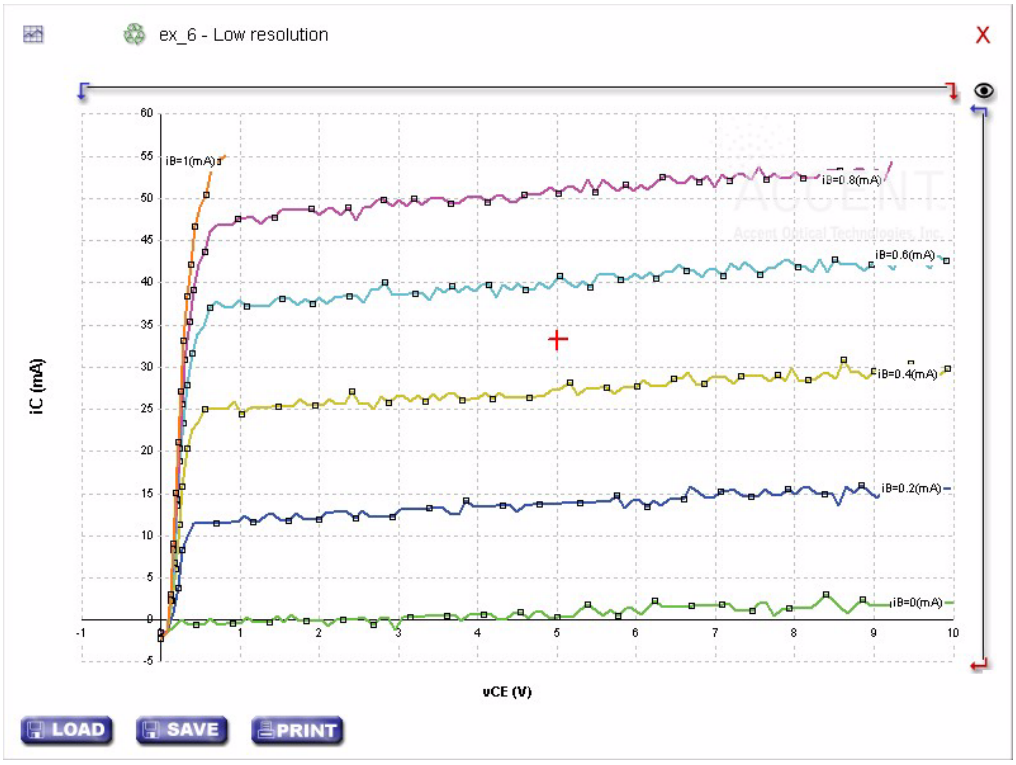


*Figure A-15: Curves produced from measurements at low resolution*



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# A.7 Example 7 - effect of forward gate current on drain current

This example is used to illustrate the self-consistent measurements which are made when the gate is forward biased sufficiently for gate current to flow in HEMTs or FETs. The intention is also to bring out some of the effects which are at first sight most unusual, such as negative drain current and gate-source conduction current which decreases as the drain voltage is increased positively.

**Background**
When gate current flows in HEMTs and FETs, the instrument has to iterate to keep the gate-source voltage constant at the specified values (e.g. 0.7V, 0.8V...). Measurement of drain current self-consistently with iteration to keep the gate-source voltage constant is undertaken when gate current flows. (As described in Section 4.5 gate current can reliably be measured only for pulse lengths of 1µs or greater.)

**Set-up**
For this demonstration, a small enhancement-mode device was used. Dynamic measurements were made starting, arbitrarily, from equilibrium (i.e. $V_{DS}$ = 0V, $V_{GS}$ = 0V). Given that gate current measurements have to be made at pulse lengths of at least 1µs (for the reasons outlined in Section 4.5), the set-up was as in Figure A-16.

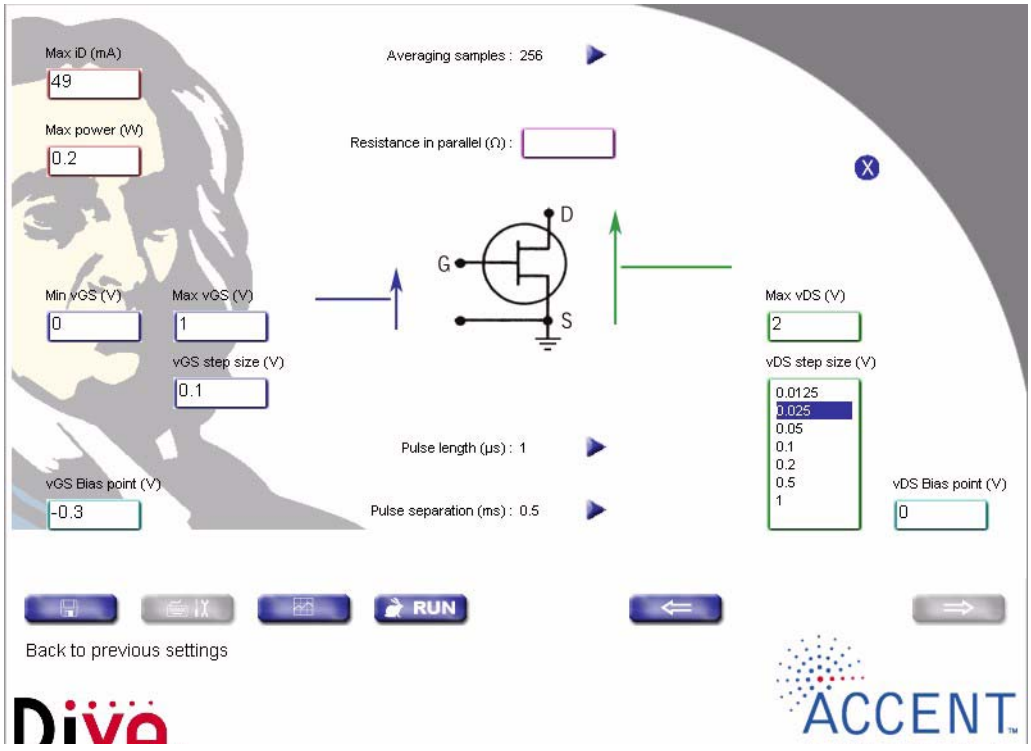


*Figure A-16: Example 7 - set-up screens*

**Results**
Figure A-17 shows the measured drain current. At small $V_{DS}$ values the drain current is negative (but the instrument's display routines cut off at zero current). Figure A-18



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shows the measured gate terminal current illustrating, among other properties, that the current is a strong function of $V_{DS}$ as well as $V_{GS}$.

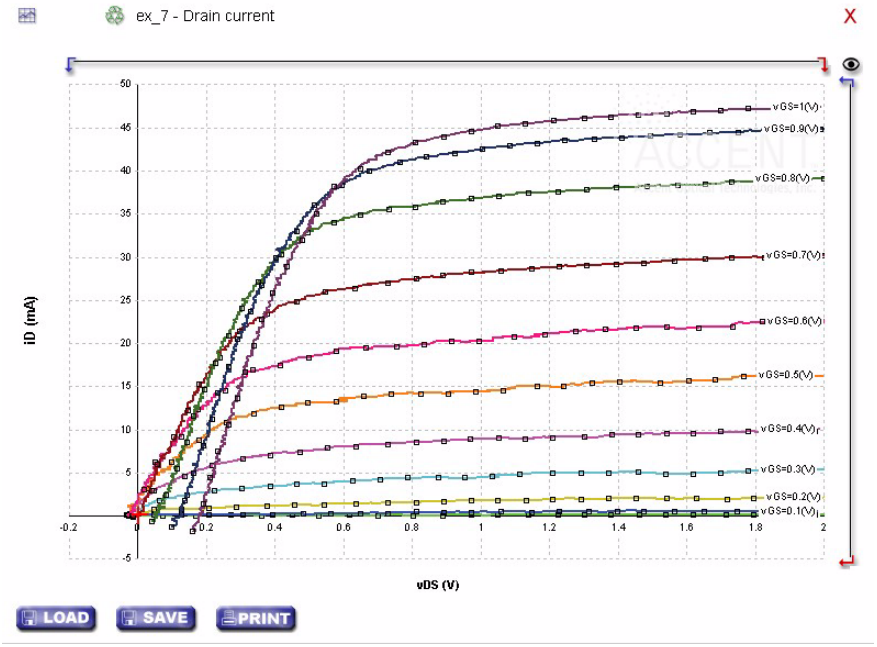


*Figure A-17: Measured drain current*

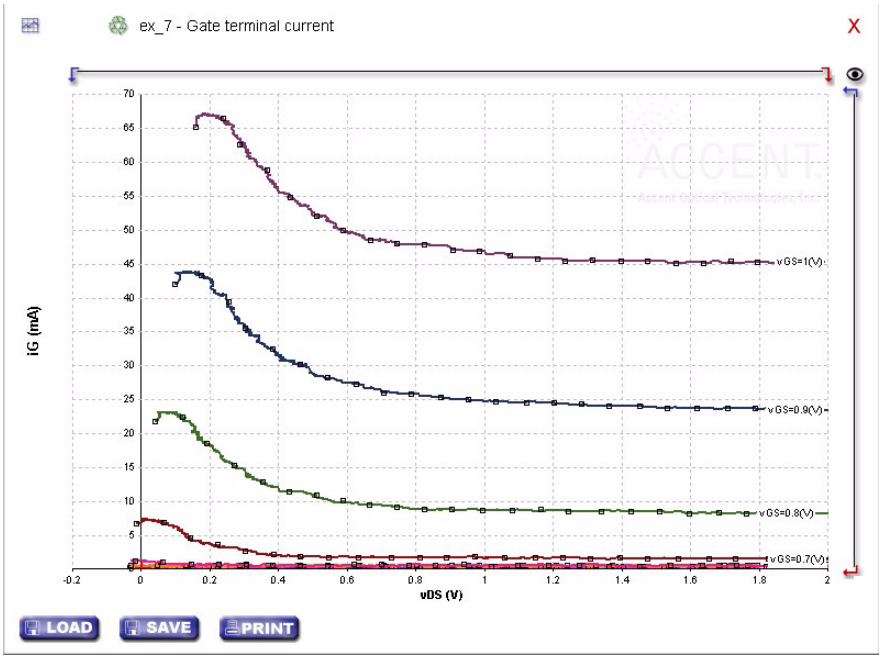


*Figure A-18: Measured gate terminal current*

**Conclusion**

Contrary to the assumption made in many of the standard large-signal models of FETs and HEMTs, the gate current is not well approximated by a simple diode giving a dependence upon $V_{GS}$ only. Secondly, the drain current of Figure A-17 is a terminal (or nodal) current, not a drain-source branch current. Thus the use of the data in Figure A-17 as a branch current in a large-signal model would be erroneous unless other adjustments are made to compensate.



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# A.8 Example 8 - detecting interaction between the device and the instrument

This example is used to illustrate that caution needs to be exercised to detect interaction between the device and the instrument which can occur when the pulse length used to make the measurements is comparable with the intrinsic response time of the transistor (in this case a bipolar).

**Background**

Some power bipolar transistors may have an intrinsic response time

$$\frac{1}{f_{-3dB}}$$

comparable with the shortest pulses the instrument uses. The response of the device may then be partly governed by time constants formed by charge storage within the device and the output resistance of the instrument - leading to the apparent anomaly that the dynamic *I(V)* characteristics measured for the device depend upon the limit that has been set for the maximum collector current (the output resistance of the "Drain or Collector" channel is automatically switched from 10Ω to 100Ω at 50mA in the D210 and D225, and at 250mA in the D265).

**Set-up**


Figure A-19 shows the set-up for the measurement. The same measurement is made twice - once with the maximum current set to 51mA (for which the output resistance at the "Drain or Collector" connector will be 10Ω), and secondly with the maximum current set to 49mA (for which the output resistance at the "Drain or Collector" connector will be 100Ω).

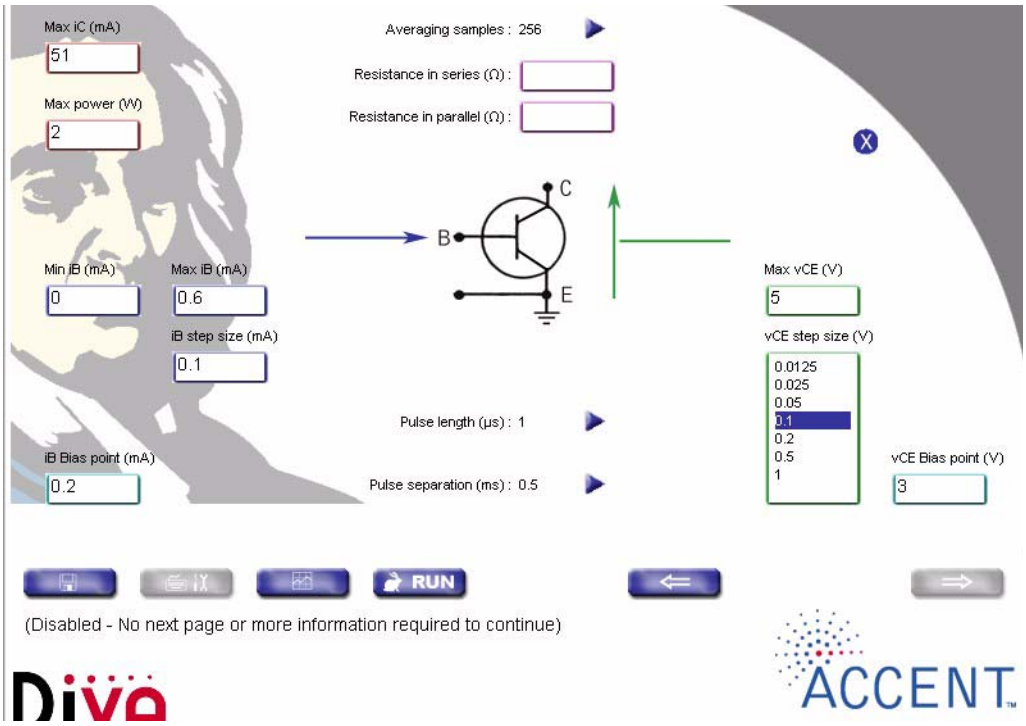


*Figure A-19: Example 8 - set-up screens*



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**Results**

Figure A-20 gives the results. At first sight the 1µs pulse-measured *I(V)* characteristics appear to depend upon the current range set, which is anomalous in the sense that the *I(V)* characteristics should be a property of the device alone - not of the method used to measure them.

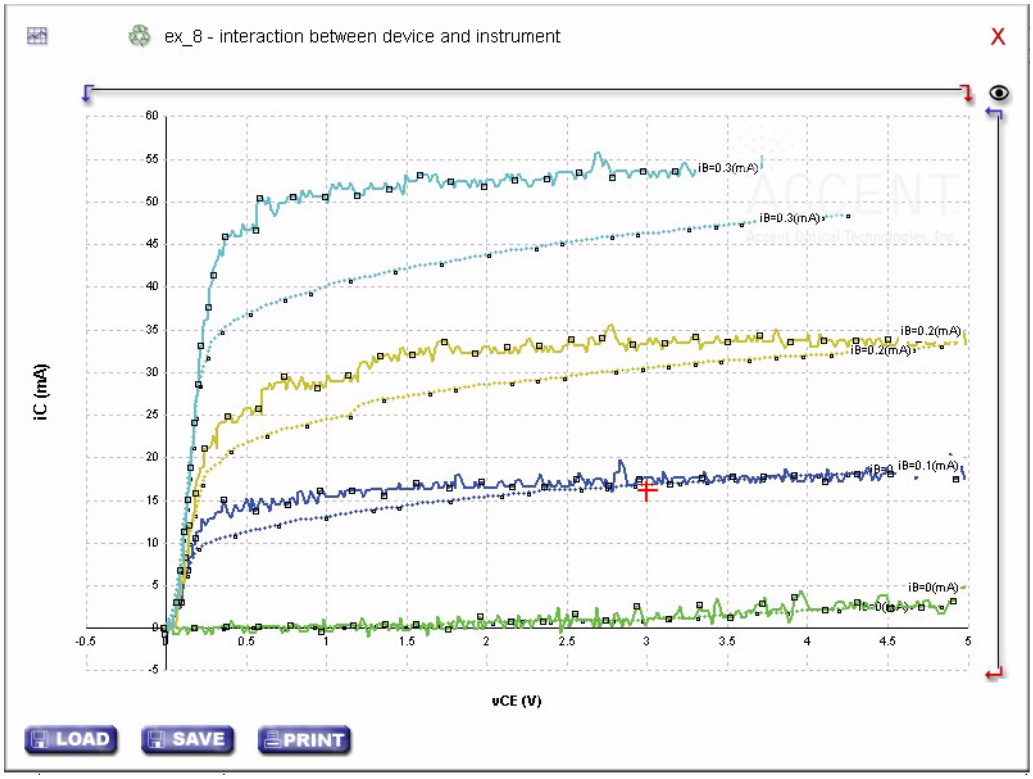


*Figure A-20: Example 8 - resulting graphs*

The apparent anomaly is explainable by the Miller effect. Figure A-21 shows a basic hybrid-π equivalent circuit for the transistor connected to a Thévenin equivalent circuit of the instrument at the collector, and a Norton equivalent of the instrument at the base.

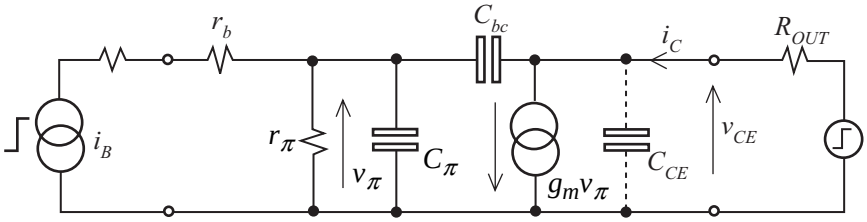


*Figure A-21: Example 8 - basic hybrid-π equivalent circuit*

Defining the voltage gain $v_{CE}/v_\pi$ as $A_v$, the Miller effect causes the capacitance $C_\pi$ to have an effective value of $(C_\pi + A_v C_{bc})$ which slows the rise of $i_C$, so $i_C$ has not settled when the measurement is made 1µs after the leading edges of the pulses are applied. An approximate analysis is:



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Given, for this transistor, $f_r = 60\text{MHz}$
and since we measure $\beta \approx 200$
then $f_{-3dB} \approx 300\text{kHz}$

Also: $$f_{-3dB} \approx \frac{1}{2\pi C_\pi r_\pi}$$

so $C_\pi r_\pi \approx 0.5\mu\text{s}$

Now $$r_\pi \approx \frac{kT}{qI_B} \approx 250\Omega$$

Therefore $C_\pi \approx 2{,}000\text{pF}$

Typically, $$\frac{C_{bc}}{C_\pi} \approx \frac{1}{30} \text{ hence } C_{bc} \approx 60\text{pF}$$

Also, $A_V \approx g_m R_{OUT}$
so for $R_{OUT} = 10\Omega$ , $A_V \approx 10$
and for $R_{OUT} = 100\Omega$ , $A_V \approx 100$

The total effective shunt capacitance at the input is

$$C_{eff} \approx C_\pi\left(1 + A_V \cdot \frac{C_{bc}}{C_\pi}\right) \approx C_\pi\left(1 + \frac{A_V}{30}\right)$$

Thus, for $R_{OUT} = 10\Omega$ , $C_{eff} \approx 4/3\ C_\pi$
but for $R_{OUT} = 100\Omega$ , $C_{eff} \approx 4C_\pi$

This shows that, for measurement ranges for which $R_{OUT} = 10\Omega$, the frequency response of the transistor is not disturbed much by attaching it to the instrument. For high-resolution-current measurements, however, for which $R_{OUT} = 100\Omega$, the frequency response of the transistor attached to the instrument is approximately four times lower than for the device as an isolated entity.

**Conclusion**
The moral is always to be on the alert for measurement corruption of the foregoing kind when dealing with devices of frequency response comparable with the frequencies present in the short pulses used by the instrument. In the example above, the most believable set of curves is the set measured with the current limit set to 51mA (for which the output resistance, $R_{OUT}$, at the "Drain or Collector" connector is 10Ω).



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# Appendix B: Supplementary notes for operation of the D225HR

**IMPORTANT**

*Device Stability*
*The D225HR machine has been engineered to measure very low currents at short pulse lengths. To this end the parasitic capacitance within the instrument has been reduced to a very low value. A consequence of this is that the capacitive load seen by the device under test when attached with short cables is very small. This is generally a good thing but, for high gain devices with a tendancy to oscillate, the oscillation problem may be worse than that on other DiVA instruments. Stability can be achieved by the application of external resistors either in series with the base or in parallel with the collector. In some circumstances using a longer cable will, by adding back in capacitance, remove device oscillation.*

## B.1 Basic method of measurement

To reduce the risk of the device-under-test oscillating, both the base and collector ports of the DiVA feed signals to the device through finite impedances. In particular, a finite source (generator) impedance is needed in the base for device stability. Consideration of Figure B-1 then shows that, in setting a prescribed value of base current, DiVA has to get two values right simultaneously: $i_B$ and $v_{BE}$ or, equivalently, $v_{BGEN}$ and $v_{BE}$ . Analogue-to-digital converters sense both voltages.

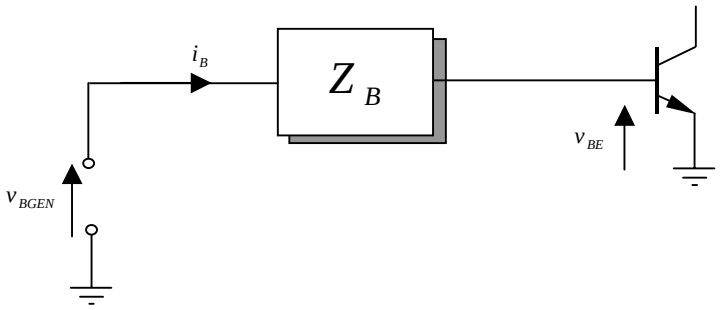


*Figure B-1: Schematic showing device-under-test driven via a finite source impedance $Z_B$*



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There are limitations imposed by the discretized nature of the sensed voltages, as summarized in Figure B-2. Accounting for the minimum voltage increment at either end of $Z_B$ determines a current setting resolution indicated on Figure B-2 as $\varepsilon i_B$. Based on this consideration alone, the voltage at the base of the transistor would fall somewhere in the range $v_{BE1}$ to $v_{BE2}$ .

If the range $v_{BE1}$ to $v_{BE2}$ is smaller than a resolution step of the A-D converter which senses and sets $v_{BE}$, and if $v_{BE1}$ to $v_{BE2}$ falls inside the range determined by one resolution step (indicated on Figure B-2 by the interval $v_{BEA}$ to $v_{BEB}$ ), then the instrument cannot set the current in the target range $\varepsilon i_B$: it can only set a base current of either $i_{BA}$ or $i_{BB}$. So, sometimes the instrument will be able to set the target current within the range $\varepsilon i_B$, in which event the resolution is determined by the conditions surrounding $Z_B$, while at other times the accuracy to which $i_B$ is set is dominated by the interaction of the converter sensing $v_{BE}$ with the turn-on characteristic of the base-emitter junction. As a result, there may be small steps or jumps in the curves which are, however, only noticeable when measuring at base currents of a few microamps.

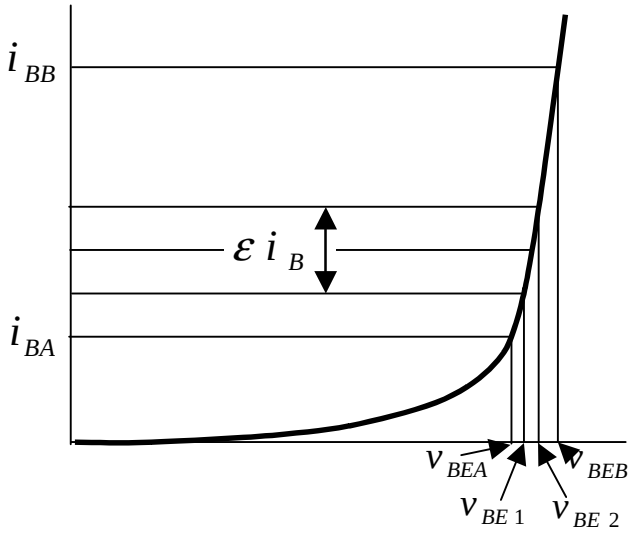


*Figure B-2: Base-emitter junction characteristic showing exaggerated base current setting and resolution constraints*

## B.2 Limits on $I_{BSTEP}$ and $t_{pulse}$

The theoretical maximum uncertainty in setting $i_B$ is ± 0.173µA (with 1.5kΩ in the base channel). Accepting an uncertainty in $i_{BSTEP}$ of 10% or less implies the minimum step size for $i_B$ should be 2µA. Figure B-3 shows a set of collector characteristics measured using 500ns pulses with 2µA base current steps.

The limitation on $t_{pulse}$ is not a property peculiar to DiVA but is fundamental: it applies to any system that makes pulsed base current measurements. It comes into play when a cable is used to connect to the base of the transistor-under-test and small base currents are set.



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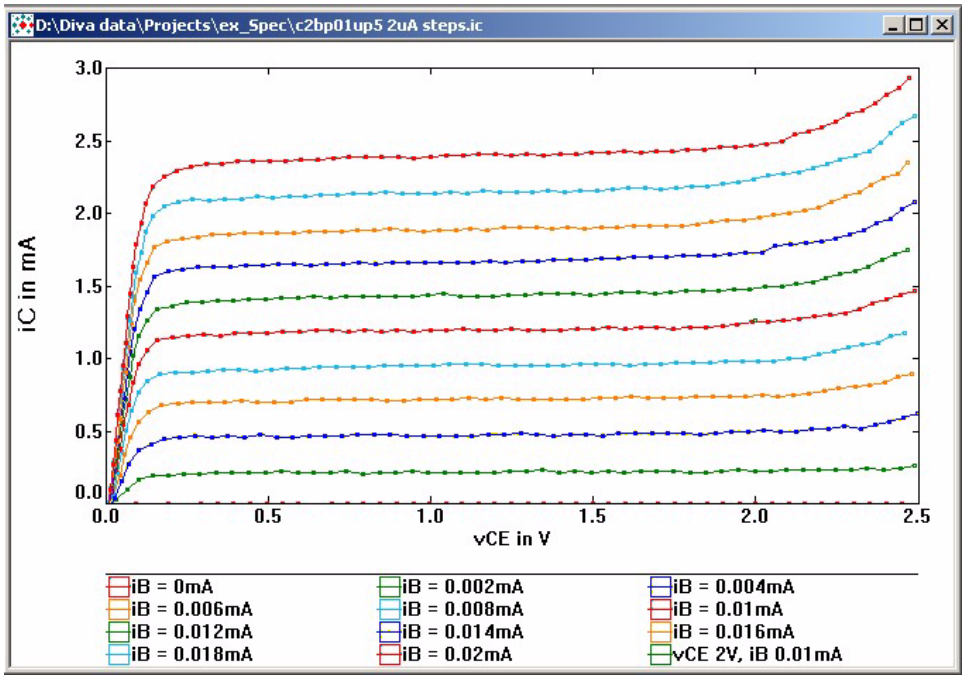


*Figure B-3: Si-Ge HBT measured with 2μA base current steps about the bias point $V_{CE}$=2V $i_B$=0.01mA*

Assuming for the base current characteristic the approximate form

$$i_B = I_0 e^{\frac{qv_{BE}}{nkT}}$$

then

$$\frac{\delta i_B}{\delta v_{BE}} = \frac{q}{nkT} \cdot i_B$$

so

$$\delta v_{BE} = \frac{nkT}{q} \cdot \frac{\delta i_B}{i_B}$$

Assuming by way of example

$i_B = 10\mu A$ $\quad \delta i_B = 5\mu A$ $\quad n \leq 3$

then

$$\delta v_{BE} = \frac{3 \times 0.025 \times 5 \times 10^{-6}}{10 \times 10^{-6}} \approx 0.04V$$

In other words, to change the base current by 5μA requires the base-emitter voltage to increase by 40mV.

Now suppose the device is connected via 1ft of 50Ω cable which has a capacitance of approximately 30pF, so the circuit is as Figure B-4.



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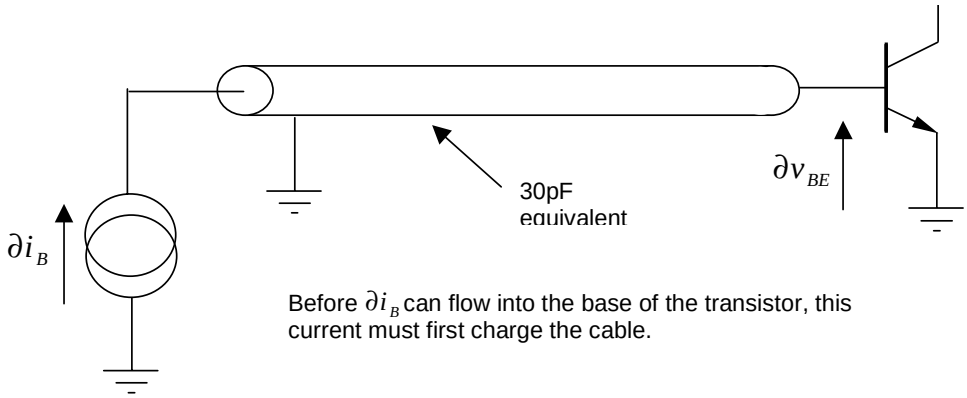
$\partial i_B$
30pF
equivalent
$\partial v_{BE}$
Before $\partial i_B$ can flow into the base of the transistor, this current must first charge the cable.

*Figure B-4: Schematic diagram for analysing the effect of cable charging in the base*

Differentiating the basic relationship for a capacitor

$$Q = C \cdot V$$

gives

$$i = C \cdot \frac{\delta V}{\delta t}$$

Re-arranging

$$\delta t = \frac{C}{i} \cdot \delta V$$

At this simple level, the time required to charge the cable is therefore

$$\delta t = \frac{30 \times 10^{-12}}{5 \times 10^{-6}} \times 0.04V = 0.24\mu s$$

In other words, the time $t_{ON}$ at which the transistor turns properly ON is 0.24µs into the pulse.

Although much simplified compared with the true position given the parasitic and stabilising reactances present in the instrument and the connecting circuitry, the foregoing analysis correctly identifies the general problem.

## B.3 Cautions and precautions in using cables

Great care is needed in setting-up measurements on bipolar transistors to recognise pitfalls in advance. Once again, the governing issues are not peculiar to DiVA, but stem from fundamental principles applicable to all such measurements

From the analysis relating to $t_{ON}$ in the preceding section, it follows that the use of a cable in the base can lead to pulse length errors. In an extreme case of a long cable and a small base current step, the cable may not have charged fully by the time the pulse ends. When the charge contained within the current pulse (being the current multiplied by the pulse length) is insufficient to charge the cable to the voltage required by the base-emmiter junction characteristic, no current flows into the base of the device-under-test, and the collector current therefore does not change.



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If a cable must be used, as for instance when probing a device on-wafer remote from the DiVA, it should be short: 1ft of 50Ω cable is tolerable if the smallest base currents (units of microamps) are avoided. Where longer cables are inescapable, 95Ω coax should be used (95Ω coax has a capacitance of approximately 1pF per inch, whereas 50Ω coax has approximately 1pF per cm).

With some HBTs, a cable may be required in the base to achieve device stability. Following the general view put forward in Figure B-1, if the gain of the device when loaded by the instrument's output impedance at the base and collector is high, microwave instability could result. Capacitance introduced by a cable in the base attenuates signals, reducing the likelihood of oscillation.

## B.4 Pulsed measurements starting from $i_B = 0$

Referring to Figure B-5, if a pulse measurement is made starting from $i_B = 0$, the cable capacitance must be charged from zero volts (corresponding to the value of $v_{BE}$ at $i_B = 0$) to whatever value of $v_{BE}$ is required to turn the transistor on, say $v_{BEON}$ . Typically, this might be 0.7V or more. Repeating the kind of simple analysis given in Section B.2 then suggests gross errors are possible because relatively hefty (current x pulse length) charge products are required to charge the cable (and any parasitic capacitance) to $v_{BEON}$ .

The answer to this problem is to bias the transistor at very low base current rather than zero. Because the $i_B(v_{BE})$ characteristic is exponential, even for very low base bias currents the base-emitter voltage is close to $v_{BEON}$ . In other words, the base-emitter bias voltage required to establish even a very small base bias current pre-charges the cable (and other parasitic capacitance in the base circuit) to a value close to, but just below, $v_{BEON}$ . The amount of charge removed from the current pulse by having to charge the cable - by whatever small increment in $v_{BE}$ is required - is then minimized.

In summary, biasing at $i_B = 0$ is best avoided. Instead, wherever practicable, dynamic $I(V)$ measurements should be made starting from a small but finite base bias current.

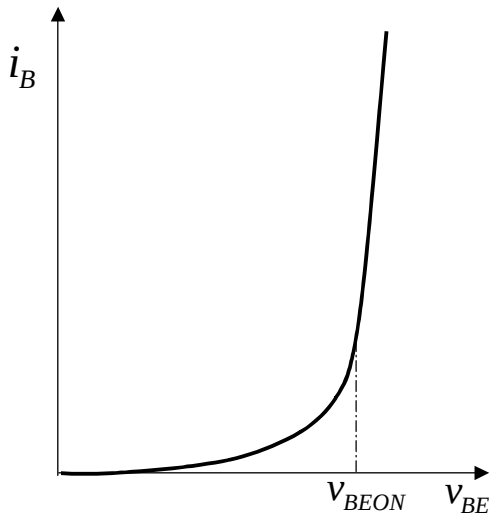


*Figure B-5: Base-emmiter junction characteristic highlighting the turn-on voltage $v_{BEON}$*



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# B.5 Voltage drops in internal impedances

From the specification, the resistive component of the output impedance of the two channels of the instrument is

| | **Base Channel** | **Collector Channel** |
|---|---|---|
| at $i_B$ _ 40µA | 1.5kΩ | 500Ω |
| at $i_B$ _ 50µA | 1kΩ | 100Ω |

These resistances cause voltage drops. For instance, the collector channel resistance leads to a “cut-back” line on plots of the measured collector current which may or may not be visible depending upon the measurement range and graph range set.

Suppose a transistor having $\beta = 100$ is driven with 10 steps of base current, each step being 40µA. At the maximum collector current of 40mA there will be a voltage drop of 20V internal to the instrument, leaving a voltage across the device of only

$$V_{CE}^{MAX} - 20\text{V} = 5\text{V}$$

# B.6 Peculiarities arising from base-collector capacitance in relatively large devices

If a relatively large device is measured using small base current steps, an apparent fault can arise which, in fact, is not a fault. Contrary to expectation, under such circumstances the measured $i_C(v_{CE},i_B)$ characteristics are not wholly dominated by conduction processes occurring in the device, but are contributed to by reactive current flow in the base-collector capacitance. Such a reactive current flows despite the relative slowness of the measurement (a 500ns pulse with a risetime of 20ns-25ns) and the seemingly small value of capacitance (of order ≤1pF in a large device).

One way of viewing the role of $C_{b'c}$ is to regard it as a Miller capacitance through which a current flows that either adds to, or subtracts from, the pulsed change in current the measurement demands. Whether the new current is additive or subtractive depends upon the polarity of the voltage pulse applied to the collector relative to the polarity applied to the base. When there is addition, the fast-pulse curves lie above those measured with slower pulses, and vice versa. The effect is demonstrated clearly in Figure B-6. It is important to stress that these differences are not attributable to the instrument in any way: they are a real property of the device.



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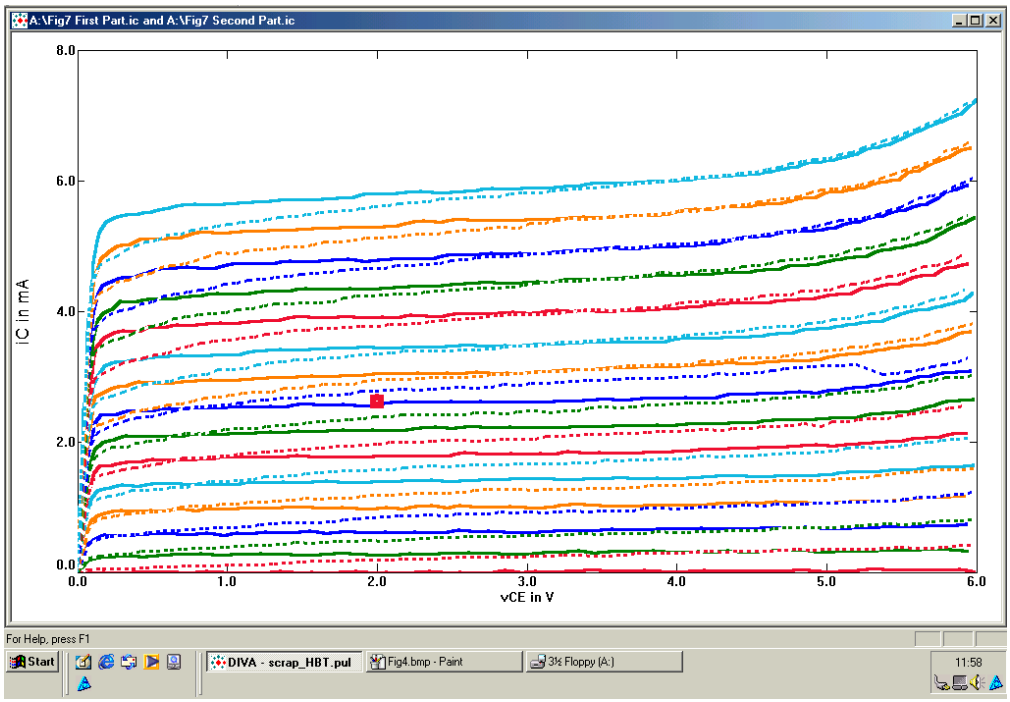


*Figure B-6: Example of slope and cross-over arising for large devices where $C_{b'c}$ is large. The solid curves are measured for 5µsec pulses; the dotted curves for 0.5µsec pulses*



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